GRINDING AND OTHER ABRASIVE PROCESSES

Lecture-06

** References:*

Chapter 26 ***(Abrasive Machining and Finishing Operations)*** *in* ***textbook*** ***(Manufacturing Engineering Technology in SI Units, 6th Edition, 2010)****, and*

Introduction

Abrasive Machining

Material removal by action of hard, abrasive particles, usually in the form of a bonded wheel

- Generally used as **finishing operations** after part geometry has been established by conventional machining

- Grinding is the most important abrasive process

Grinding Wheel

Differences between machining and grinding

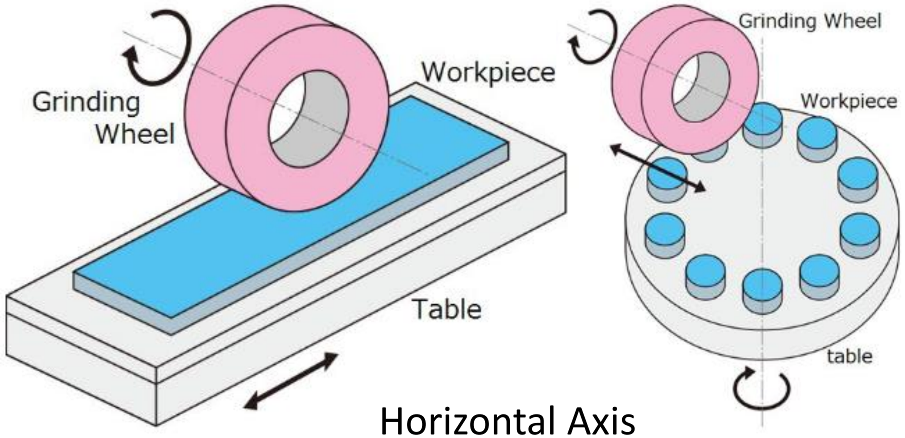
Machining	Grinding
1. Bulk material removal process (high MRR).	1. Surface finishing process (low MRR).
2. Achievable surface finish is below 10µm.	2. Improved finish can be obtained (0.5 – 2 µm).
3. Poor accuracy and tolerance is offered.	3. High accuracy and tolerance is achievable.
4. Cutting tool is made of metallic (carbon steel, HSS, etc.) as well as non-metallic materials (cBN, diamond, ceramics, etc.).	4. Grinding wheel is made of abrasives like alumina, silica, diamond, cBN, etc., which are bonded in a suitable medium (like resin).
5. Cutting tool has pre-defined geometry.	5. Abrasives has random geometry.
6. Rake angle usually varies from -15° to +15°.	6. Rake angle may vary from -75° to +75°.
7. Usually each main cutting edge of the tool actively and equally participates in material removal action.	7. Only few (about 1%) abrasive grits actually engage in material removal action (shearing). Many don't even touch the workpiece.
8. Specific energy consumption is lower.	8. Specific energy consumption is high.

www.difference.minaprem.com

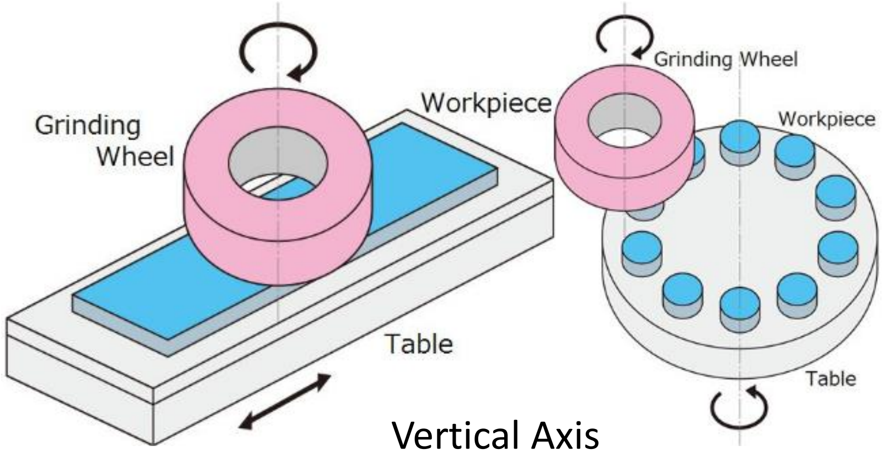
Abrasive Machining

- Various Grinding processes

Surface grinding

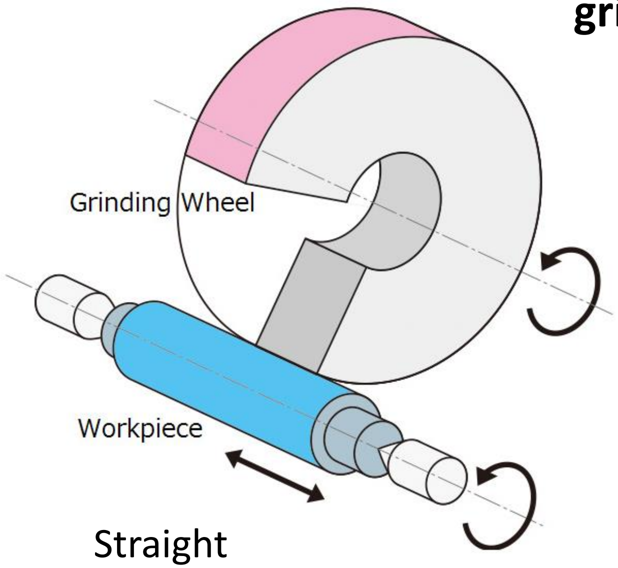


Horizontal Axis

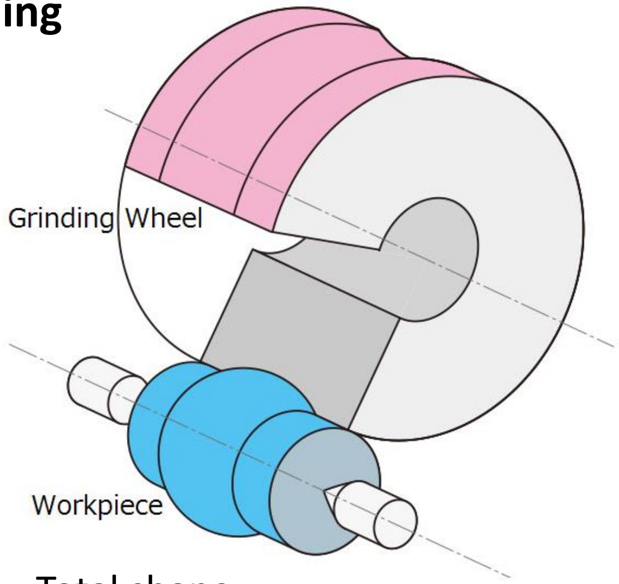


Vertical Axis

Cylindrical grinding

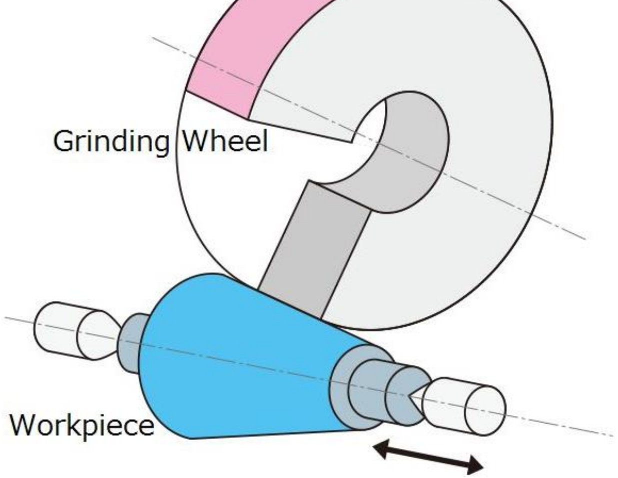


Straight

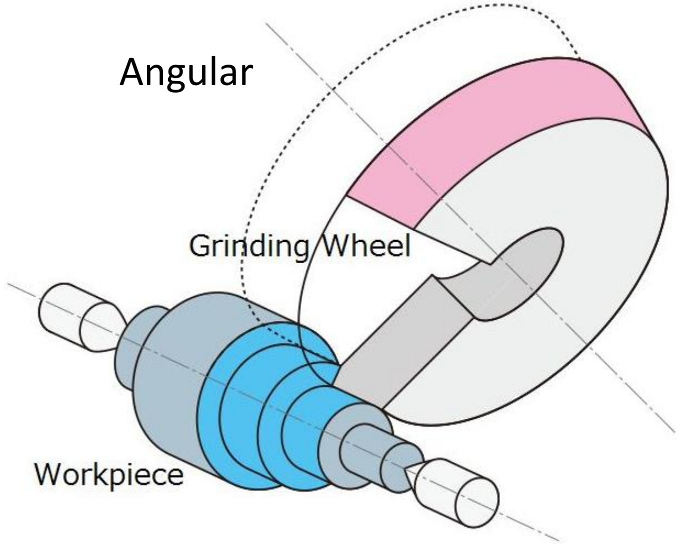


Total shape

Taper



Angular

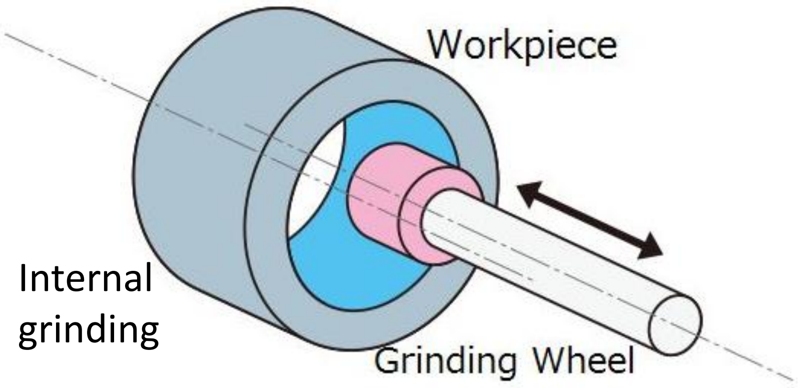


Abrasive Machining

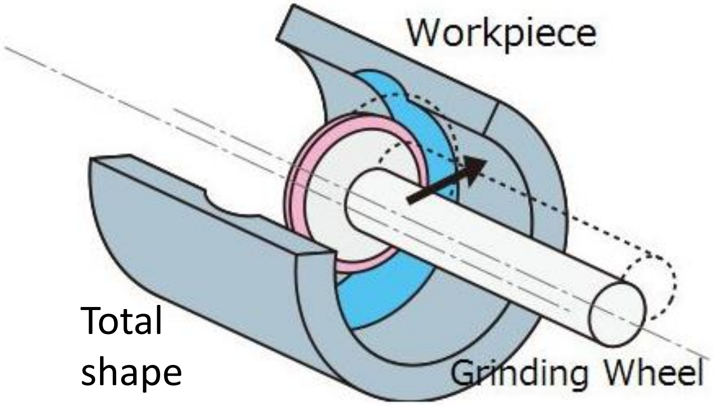
- Various Grinding processes (cont.)

Internal grinding

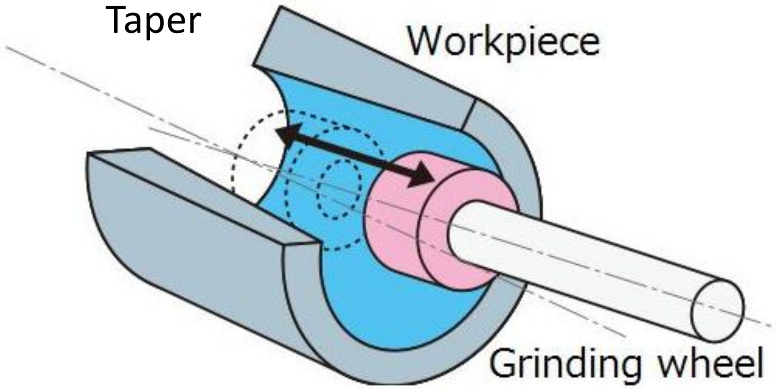
Internal grinding



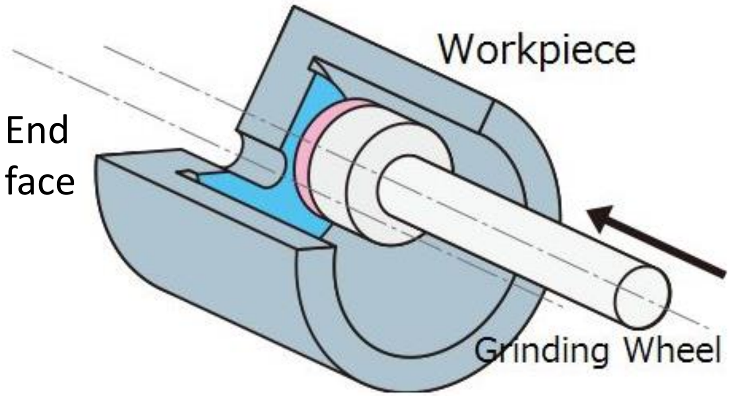
Total shape



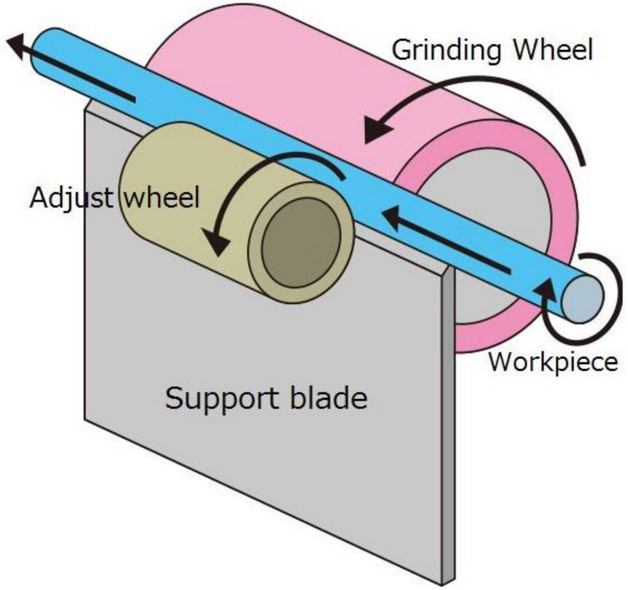
Taper



End face

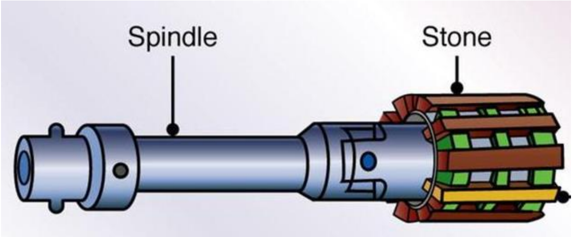


Centerless grinding

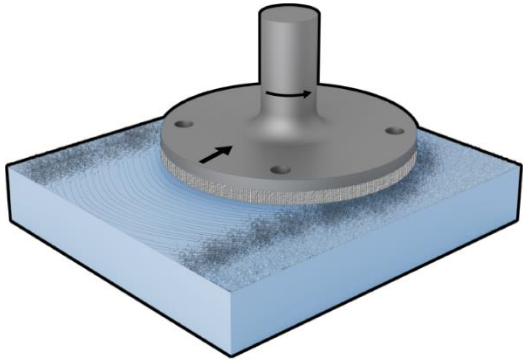


Abrasive Machining (cont.)

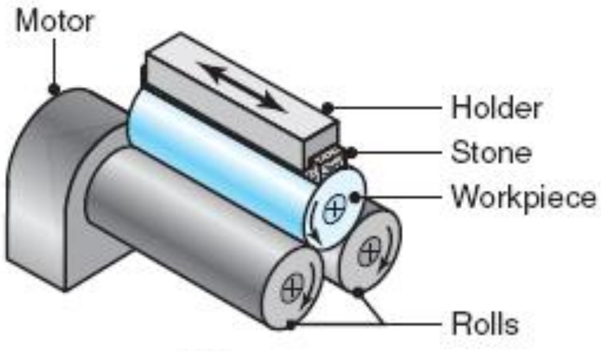
- Other abrasive processes:
  honing, lapping, superfinishing, polishing, and buffing



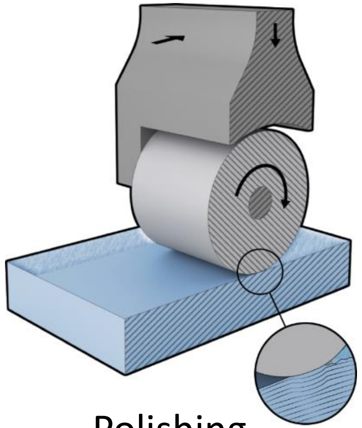
Honing operation



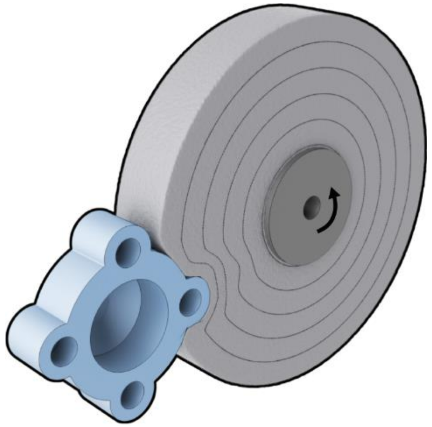
Lapping operation



Superfinishing operation



Polishing operation



Buffing operation

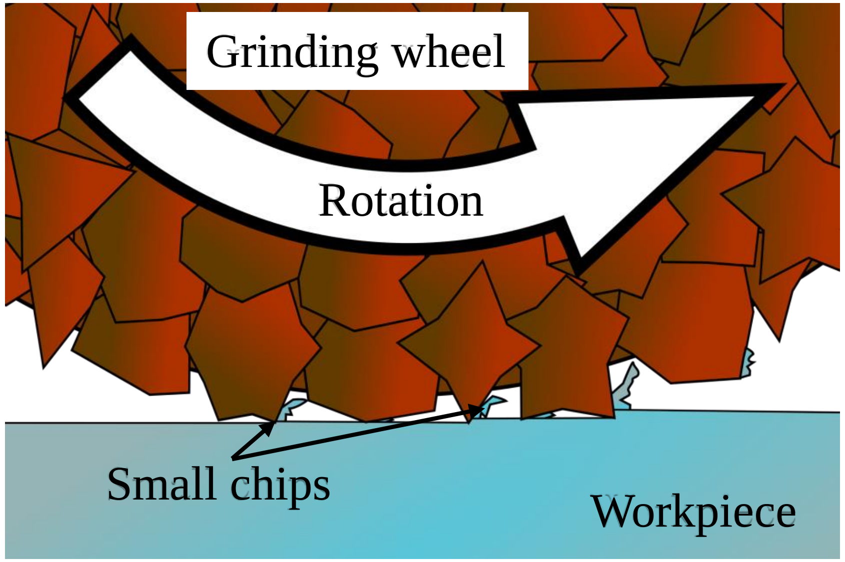
Why Abrasive Processes are Important

- Can be used on all types of materials
- Some can produce extremely fine surface finishes, to 0.025 μm (1 μ-in)
- Some can hold dimensions to extremely close tolerances

Grinding

Material removal process in which abrasive particles are contained in a bonded grinding wheel that operates at very high surface speeds

- Grinding wheel are usually disk-shaped and precisely balanced for high rotational speeds
- Grinding process involves abrasives which remove small amounts of material from a surface through a cutting process that produces tiny chips

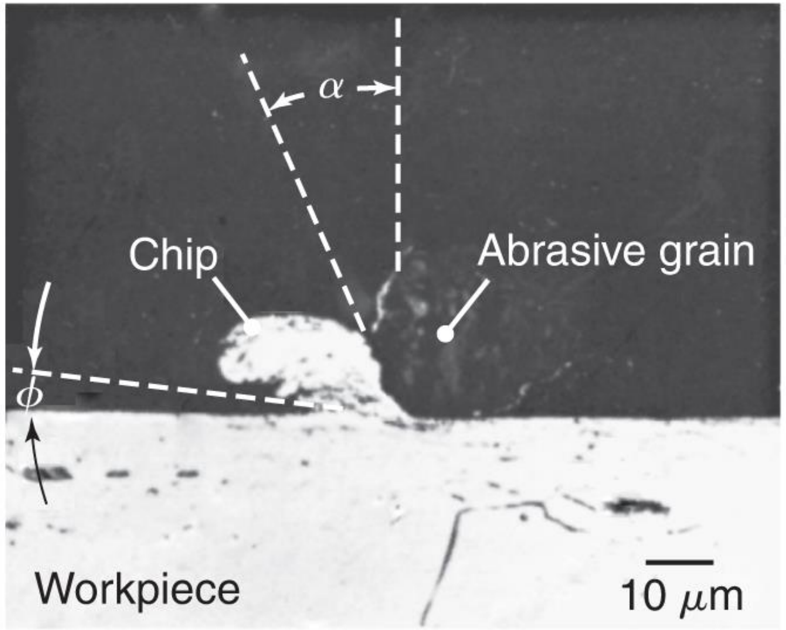


Ceramic Grain

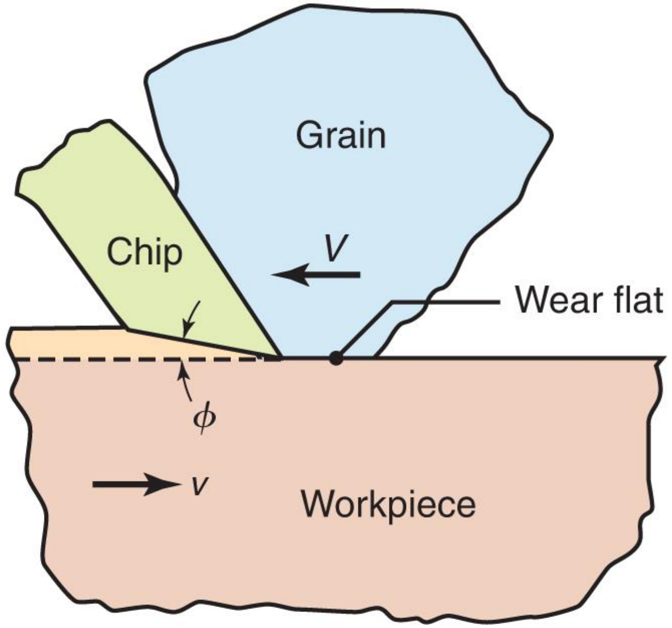
https://www.youtube.com/watch?v=nNDIm8eLrQ8

Grinding

Grinding is a chip-removal process that uses an individual abrasive grain as the cutting tool



(a)

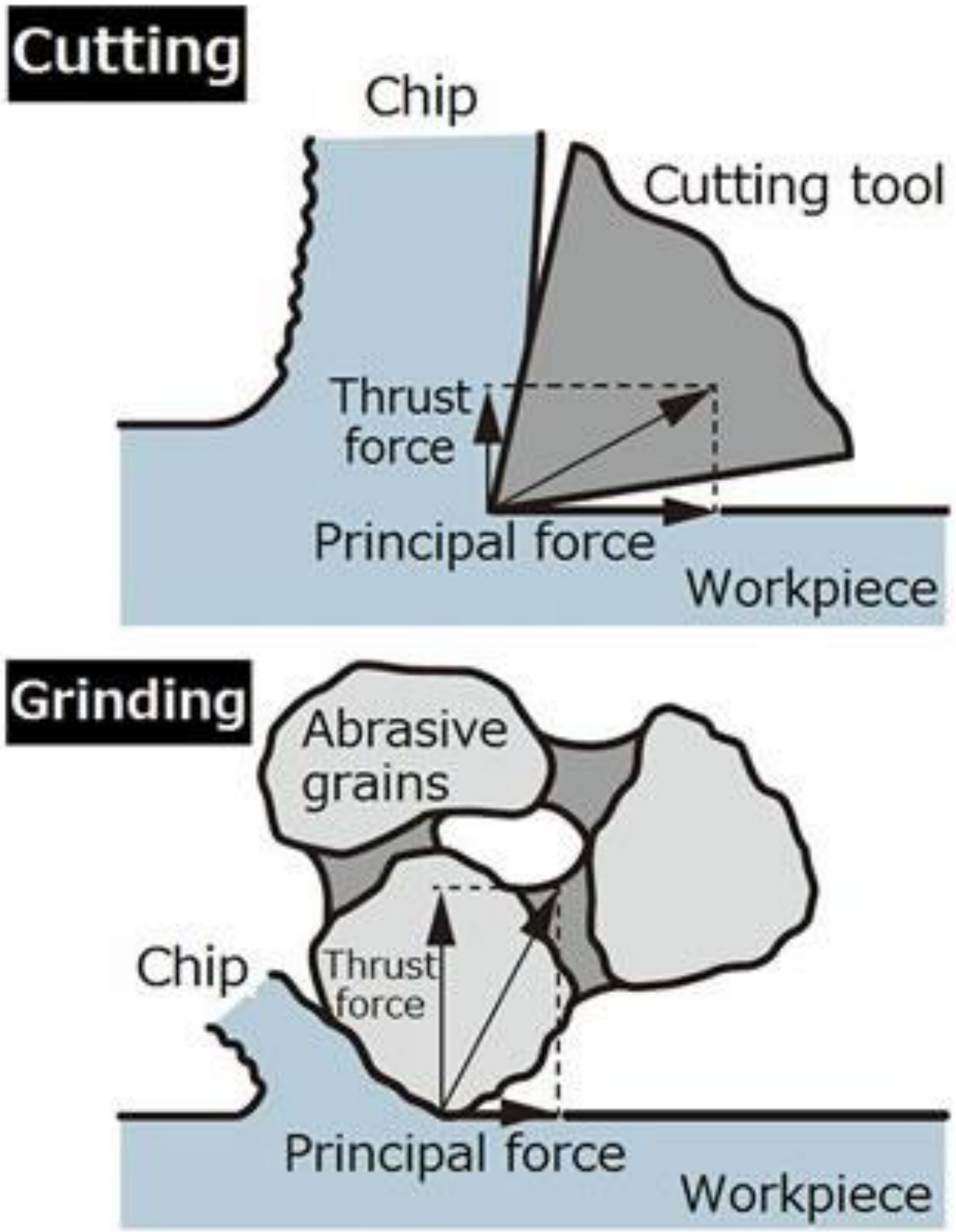


(b)

(a) Grinding chip being produced by a single abrasive grain; note the large negative rake angle of the grain.

(b) Schematic illustration of chip formation by an abrasive grain with a wear flat; note the negative rake angle of the grain and the small shear angle.

Source: Figure 26.9, Ch26, Textbook


Cutting
Chip
Cutting tool
Thrust force
Principal force
Workpiece
Grinding
Abrasive grains
Chip
Thrust force
Principal force
Workpiece

Grinding

Grinding applications include:

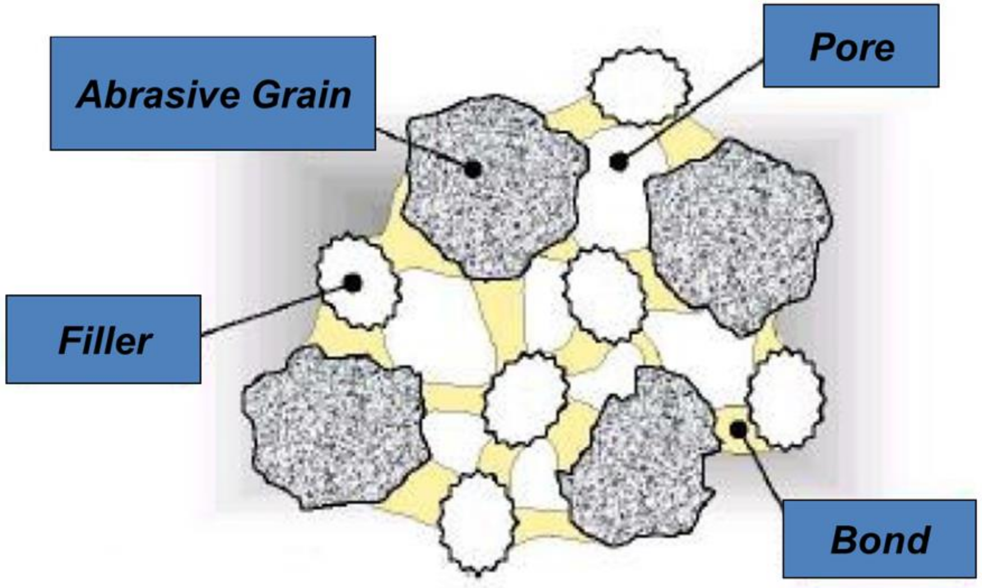
1. Finishing of ceramics and glasses
2. Cutting off lengths of bars, structural shapes, masonry and concrete
3. Removing unwanted weld beads and spatter
4. Cleaning surfaces with jets of air or water containing abrasive particles

ground-back piece of welded tube

The Grinding Wheel

Consists of abrasive particles and bonding material

- Abrasive particles accomplish cutting
- Bonding material holds particles in place and establishes shape and structure of wheel



The Grinding Wheel

The Grinding Wheel

The Grinding Wheel

Source: https://www.chris-marine.com/product/grinding-wheels/

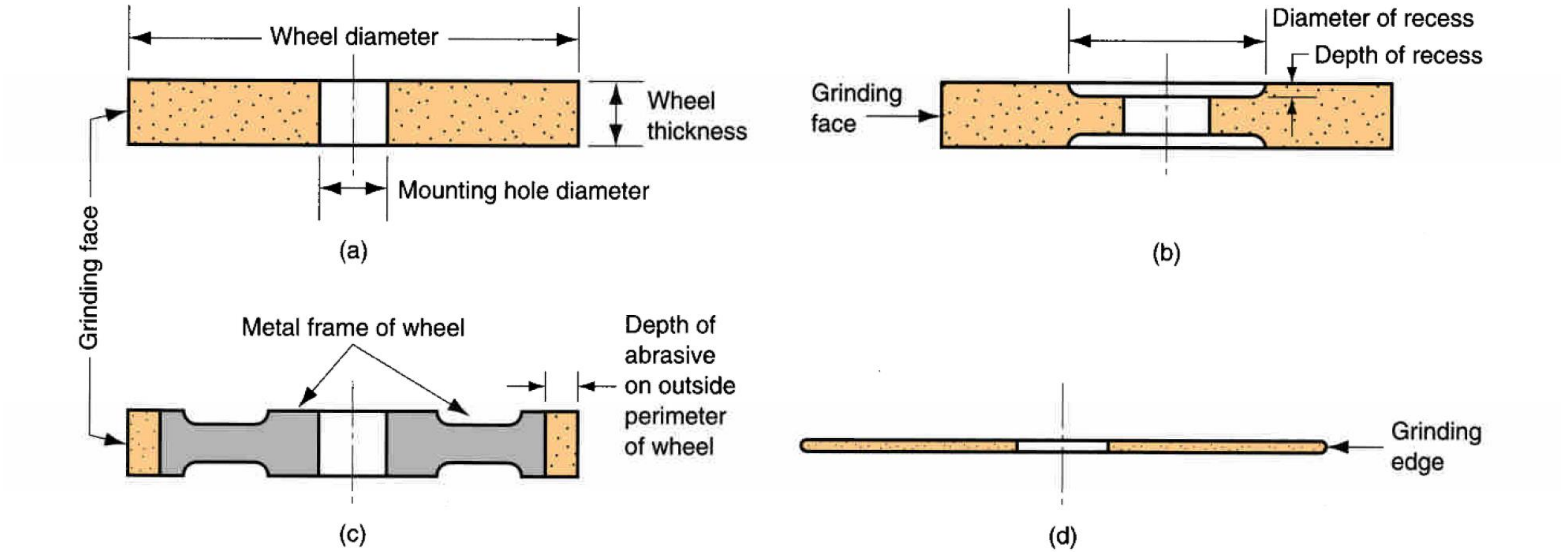


Figure 25.2 - Some of the standard grinding wheel shapes:

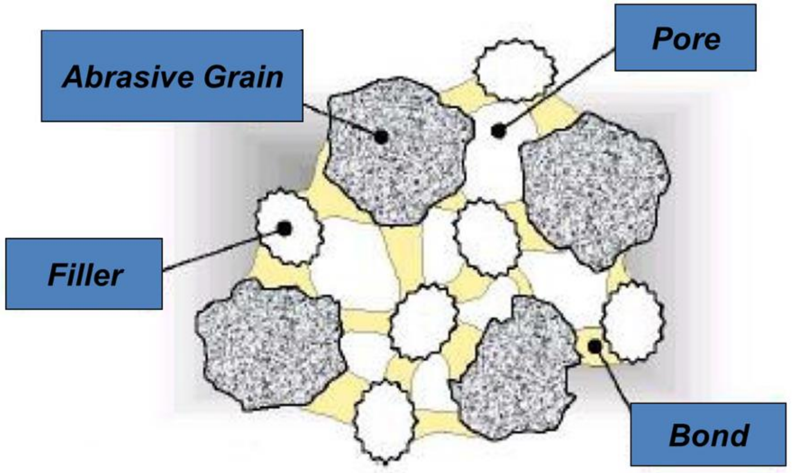
(a) straight, (b) recessed two sides, (c) metal wheel frame with abrasive bonded to outside circumference, (d) abrasive cut- off wheel

Grinding Wheel Parameters

Grinding Wheel Parameters

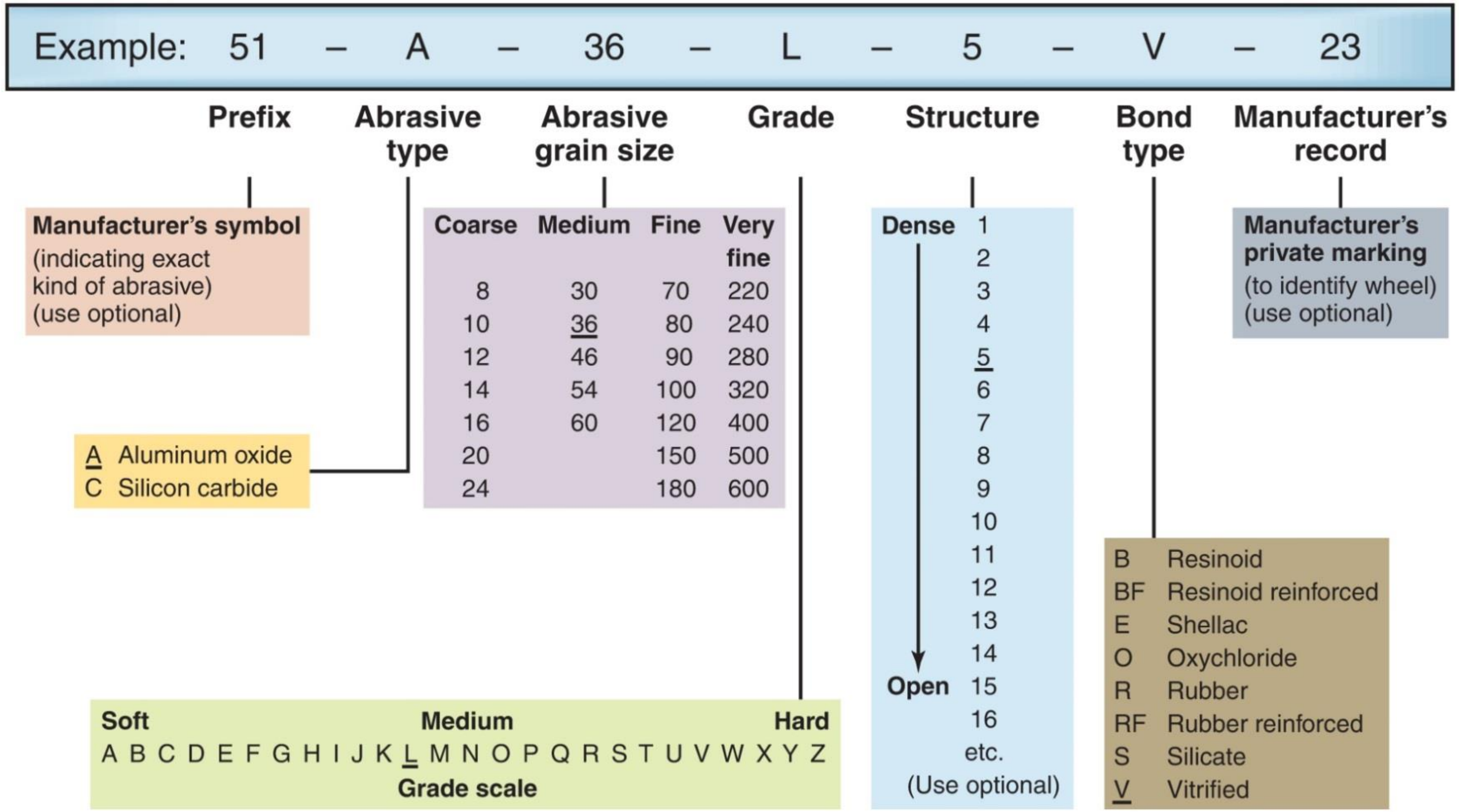
1. **Abrasive** type (material)
2. **Grain size / grit size**
3. **Bond**ing type (material)
4. Wheel **grade**
5. Wheel **structure**

Grinding Wheel



Grinding Wheel Parameters

- Due to their high cost, only small volume wheels consist of abrasives
- Bonded abrasives are indicated by the type of abrasive, grain size, grade, structure, and bond type

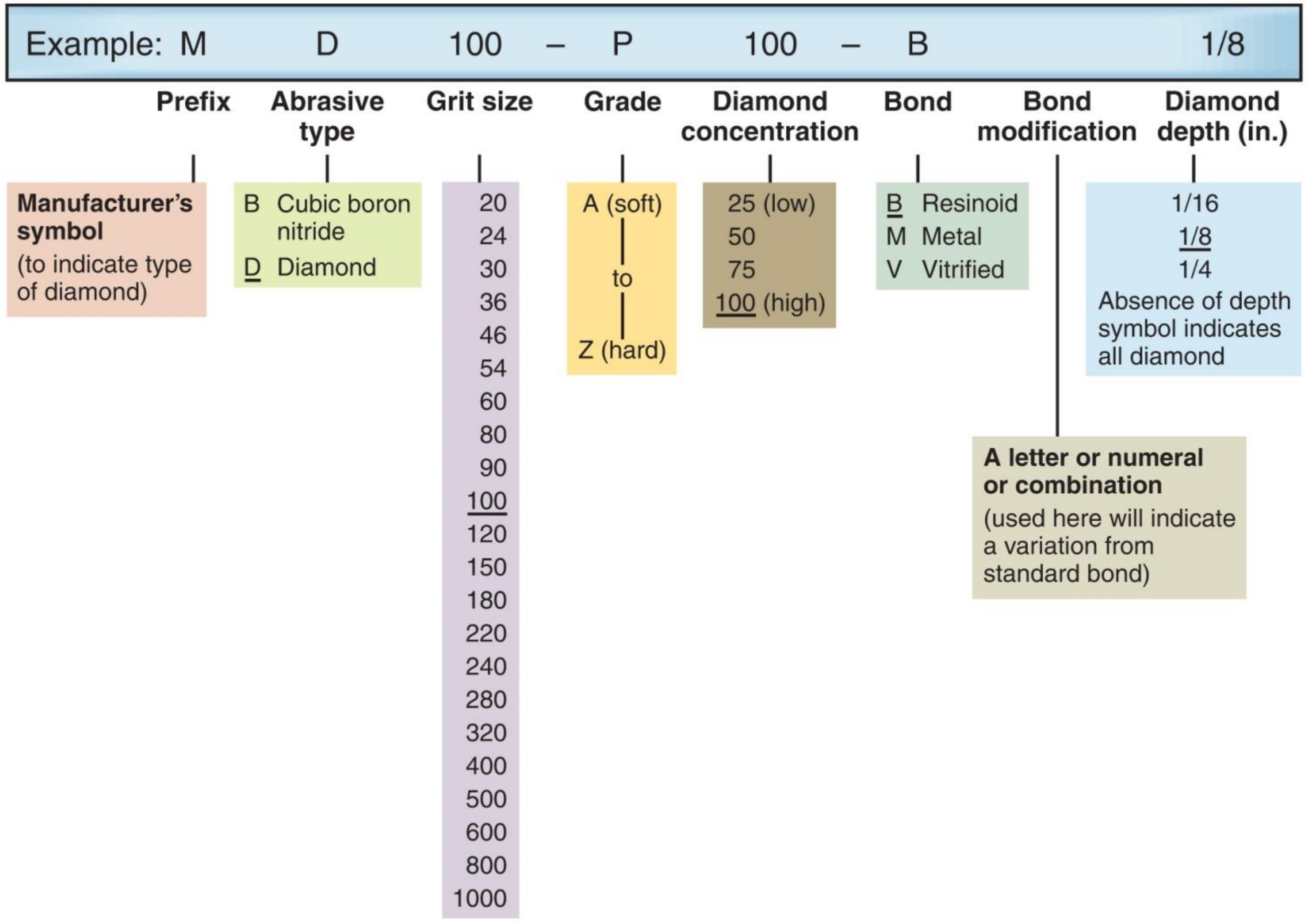


Standard marking system for aluminum-oxide and silicon-carbide bonded abrasives

Source: Figure 26.7, Ch26, Textbook

Grinding Wheel Parameters

Cost of grinding wheels depends on the type and size of the wheel

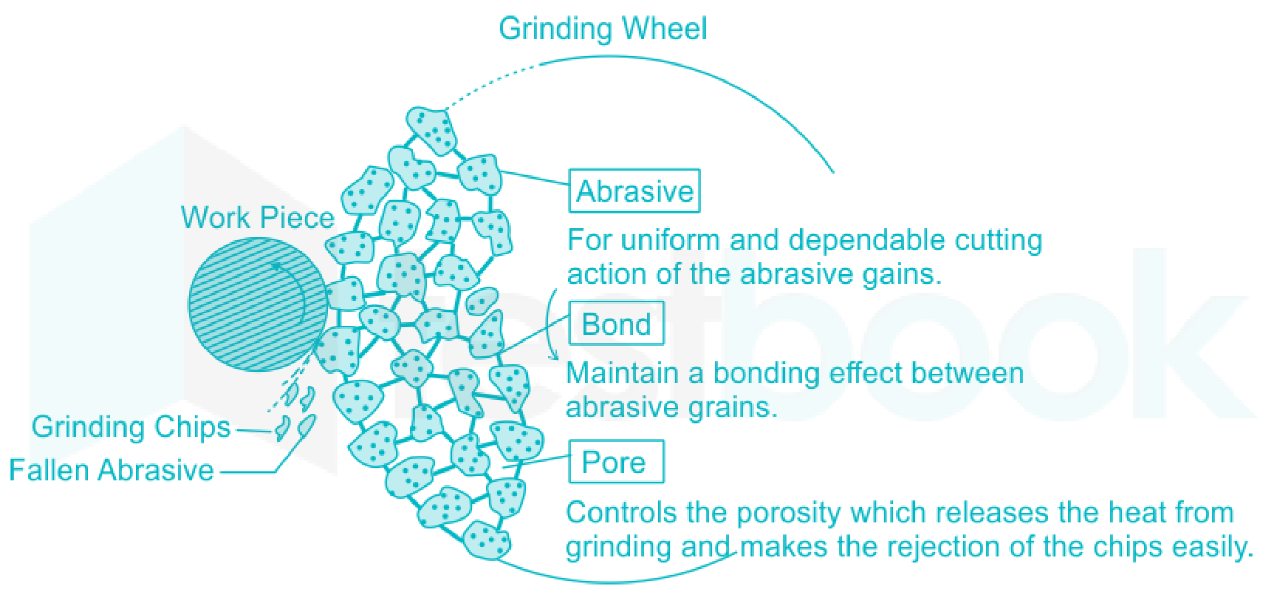


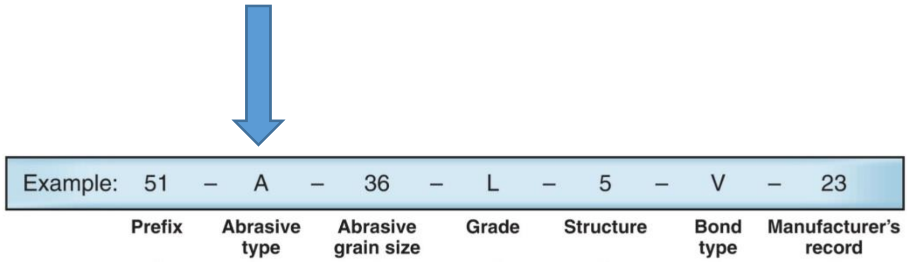
Standard marking system for cubic boron nitride and diamond bonded abrasives

Source: Figure 26.8, Ch26, Textbook

1. Abrasive Material Properties

- High hardness
- Wear resistance
- Toughness
- **Friability** - capacity to fracture when cutting edge dulls,
  so a new sharp edge is exposed
  (aka self-sharpening)

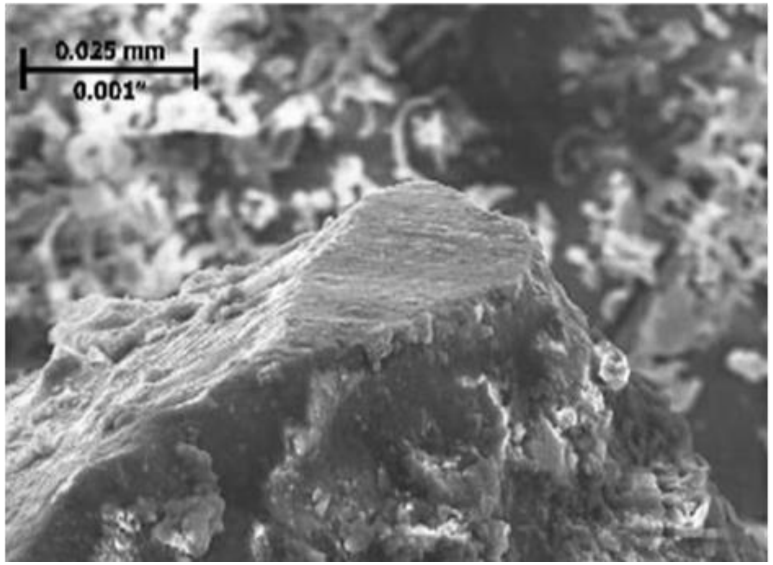




1. Abrasive Material Properties

Abrasive–workpiece-material Compatibility

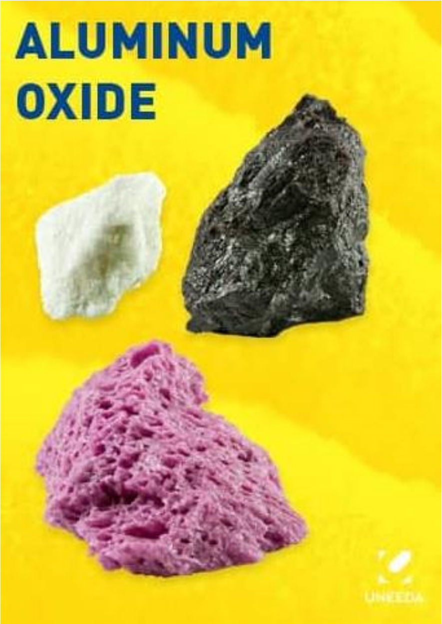
- Affinity of an abrasive grain to the workpiece material is important
- The less the reactivity of the two materials, the less wear and dulling of the grains occur during grinding

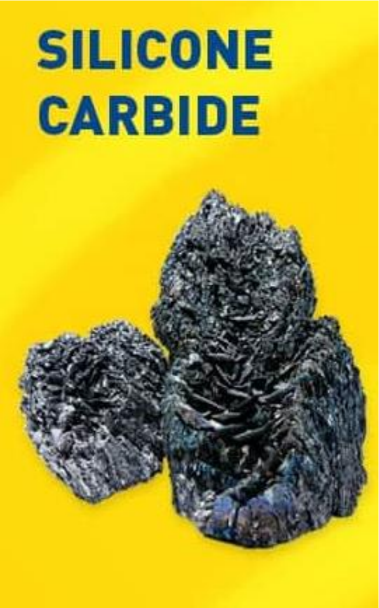


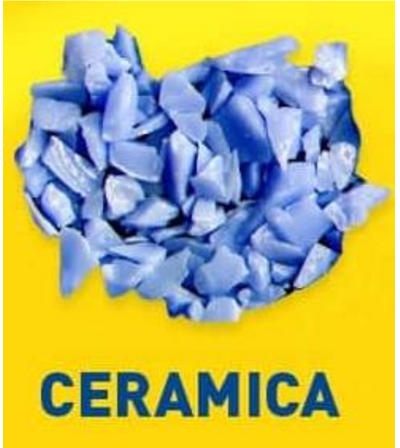
A dull grit in a worn, 46-mesh, vitrified-bond, Al_2O_3 grinding wheel

1. Traditional Abrasive Materials

- ***Aluminum oxide*** (Al_2O_3) - most common abrasive
  - Used to grind steel and other ferrous high-strength alloys
- ***Silicon carbide*** (SiC) - harder than Al_2O_3 but not as tough
  - Used on aluminum, brass, stainless steel, some cast irons and certain ceramics







1. Newer Abrasive Materials

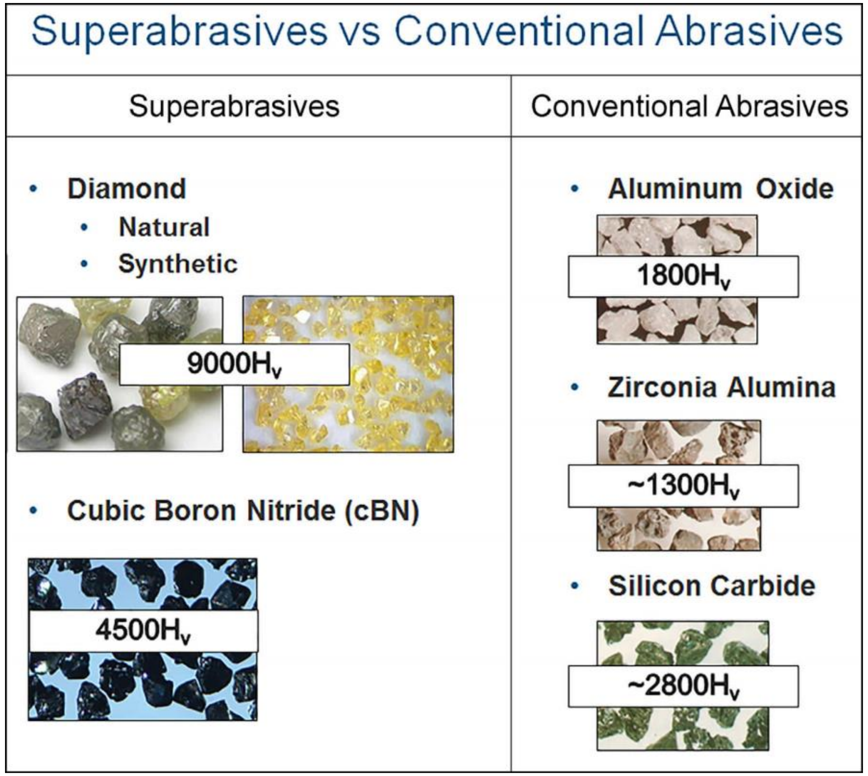
- *Cubic boron nitride (cBN)* – very hard, very expensive
  - Suitable for steels
  - Used for hard materials such as hardened tool steels and aerospace alloys (e.g., Ni-based alloys)
- ***Diamond*** – Even harder, very expensive
  - Occur naturally and also made synthetically
  - Not suitable for grinding steels
  - Used on hard, abrasive materials such as ceramics, cemented carbides, and glass

brazed "super-abrasive" tools

1. Hardness of Abrasive Materials

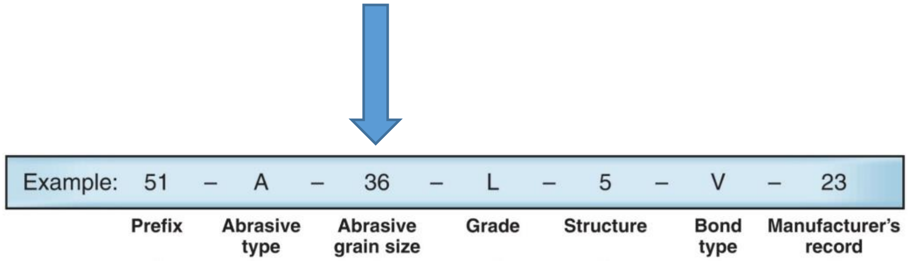
Ranges of Knoop Hardness for Various Materials and Abrasives

Common glass	350–500	Titanium nitride	2000
Flint, quartz	800–1100	Titanium carbide	1800–3200
Zirconium oxide	1000	Silicon carbide	2100–3000
Hardened steels	700–1300	Boron carbide	2800
Tungsten carbide	1800–2400	Cubic boron nitride	4000–5000
Aluminum oxide	2000–3000	Diamond	7000–8000



2. Grain Size

- Small grit sizes produce better finishes
- Larger grit sizes permit larger material removal rates
- Harder work materials require smaller grain sizes to cut effectively
- Softer materials require larger grit sizes



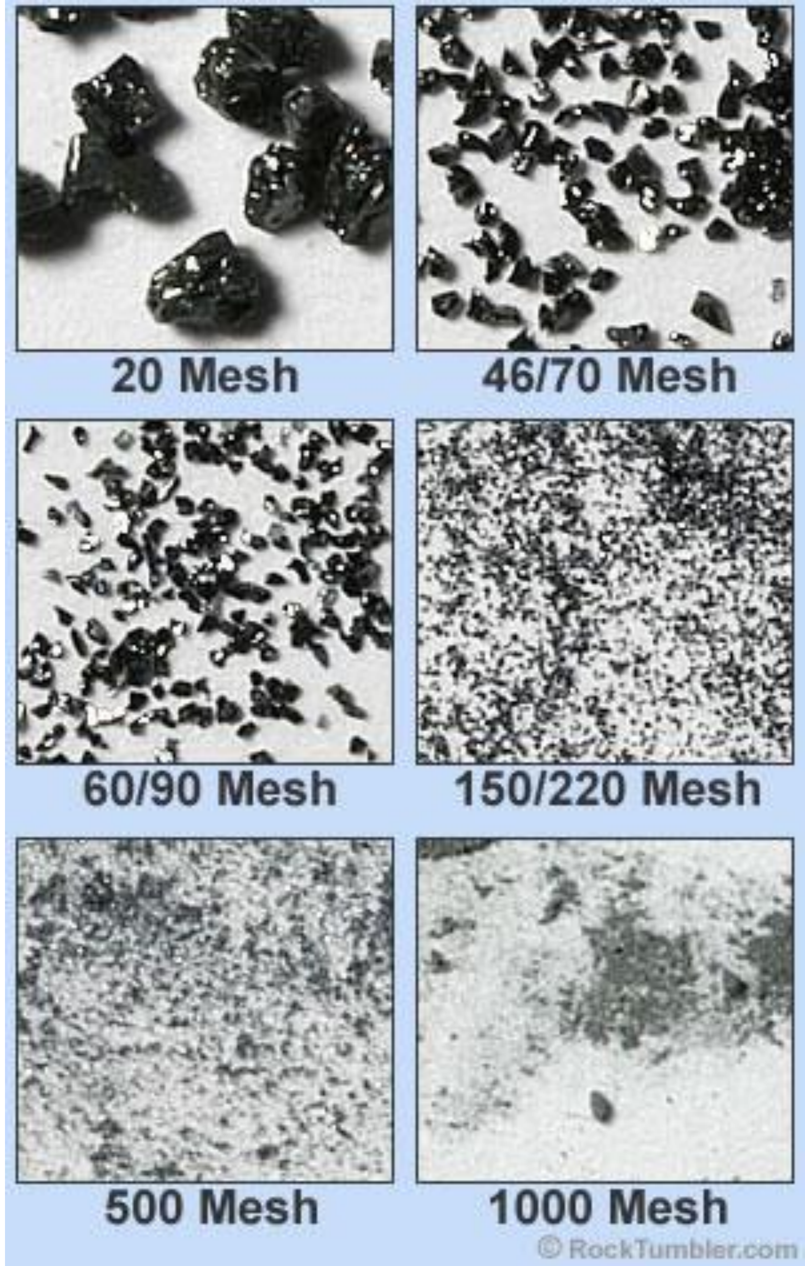
2. Grain Size

- Abrasives are very small when compared to the size of cutting tools and inserts
- Abrasives have sharp edges and allow removal of small quantities of material
- Very fine surface finish and dimensional accuracy can be obtained using abrasives as tools
- Size of an abrasive *grain* is identified by a **grit number**
- Smaller the grain size, larger the grit number

2. Measurement of Grain Size

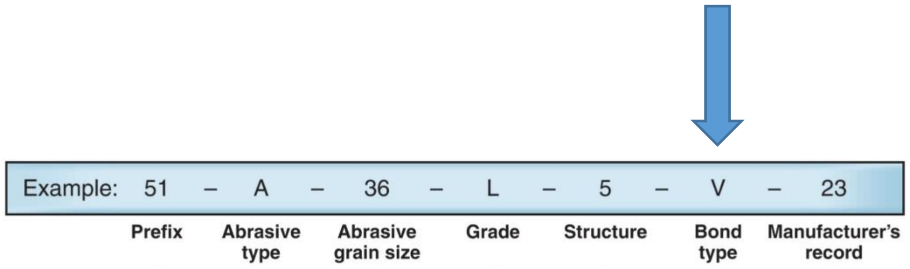
Grit size is measured using a screen mesh procedure

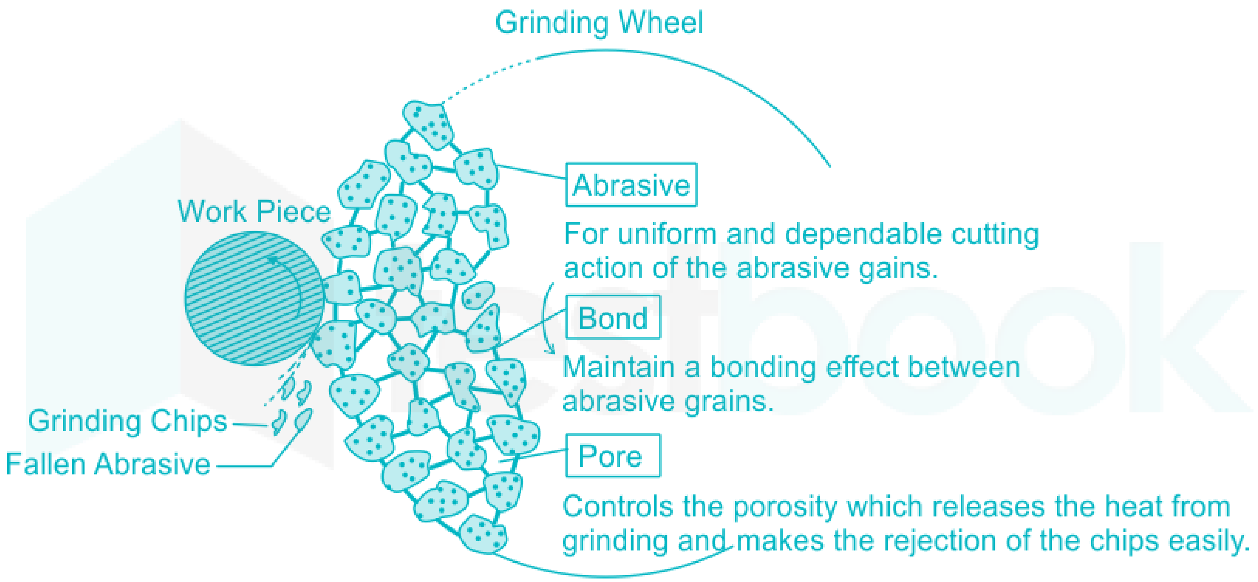
- Smaller grit sizes: indicated by larger numbers in the screen mesh procedure and vice versa
- Grain sizes in grinding wheels typically range between 8 (very coarse) and 250 (very fine)



3. Bonding Material Properties

- Must withstand centrifugal forces and high temperatures
- Must resist shattering during shock loading of wheel
- Must hold abrasive grains rigidly in place for cutting yet allow worn grains to be dislodged so new sharp grains are exposed

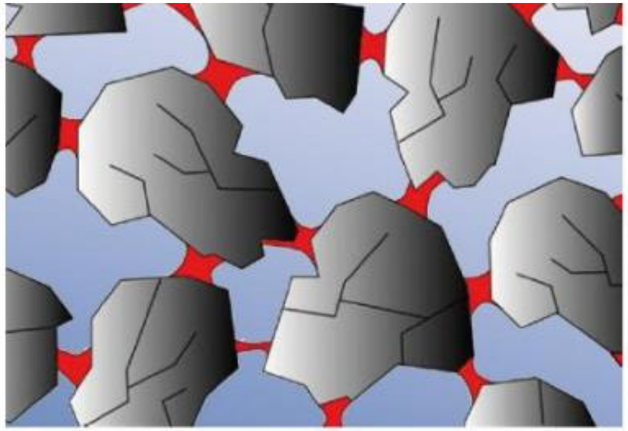




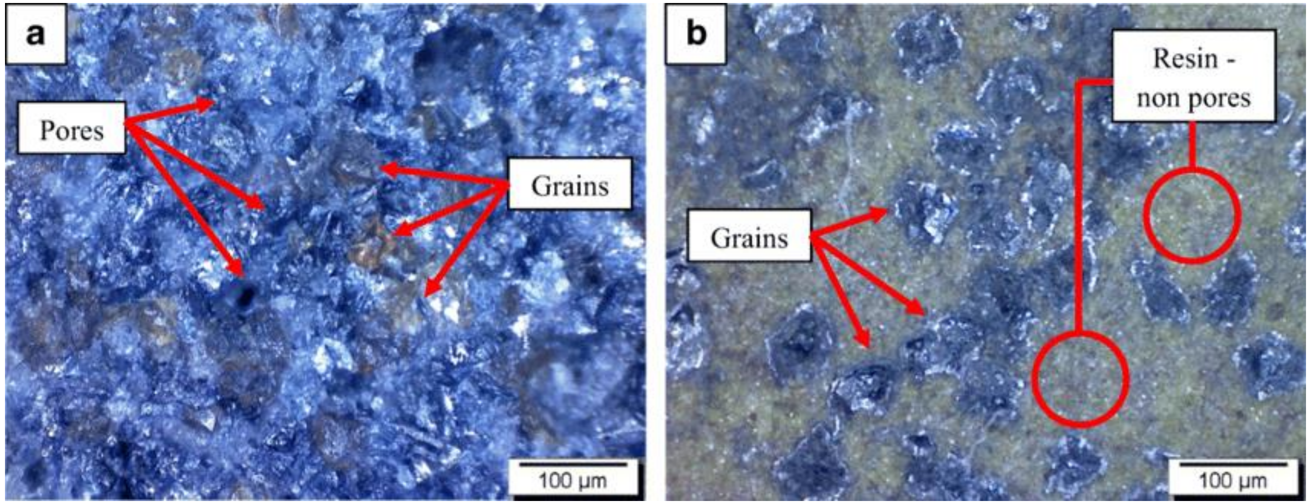
3. Bonding Material Properties

- Common types of bonds:

1. **Vitrified**:
   - Consist of feldspar (alumino-silicate) and clays
   - Strong, stiff, porous, and resistant to oils, acids, and water
2. **Resinoid:**
   - Bonding materials are *thermosetting resins*
   - Resinoid wheels are more flexible than vitrified wheels



Structure with the VITRA high-performance, low-fired bond



Active surface of vitrified (a) and resinoid (b) bond grinding wheel (× 200 magnification)

3. Bonding Material Properties

3. **Reinforced Wheels:**
   - Consist of layers of *fiberglass mats* of various mesh sizes

4. **Thermoplastic:**
   - Used in grinding wheels
   - With sol-gel abrasives bonded with thermoplastics

5. **Rubber:**
   - Using powder-metallurgy techniques
   - Lower in cost and are used for small production quantities

reinforced resinoid wheels

sol-gel grinding wheel

rubber bond abrasive wheel

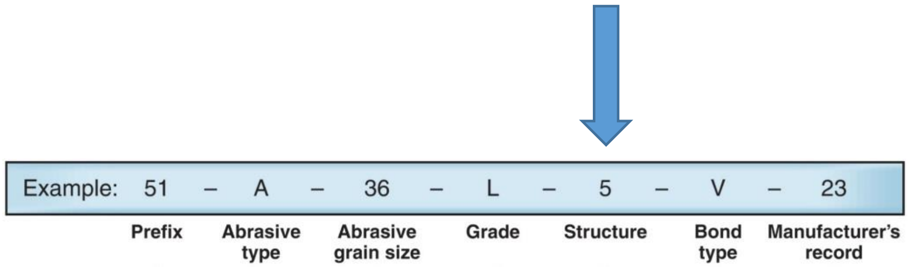
4. Wheel Structure

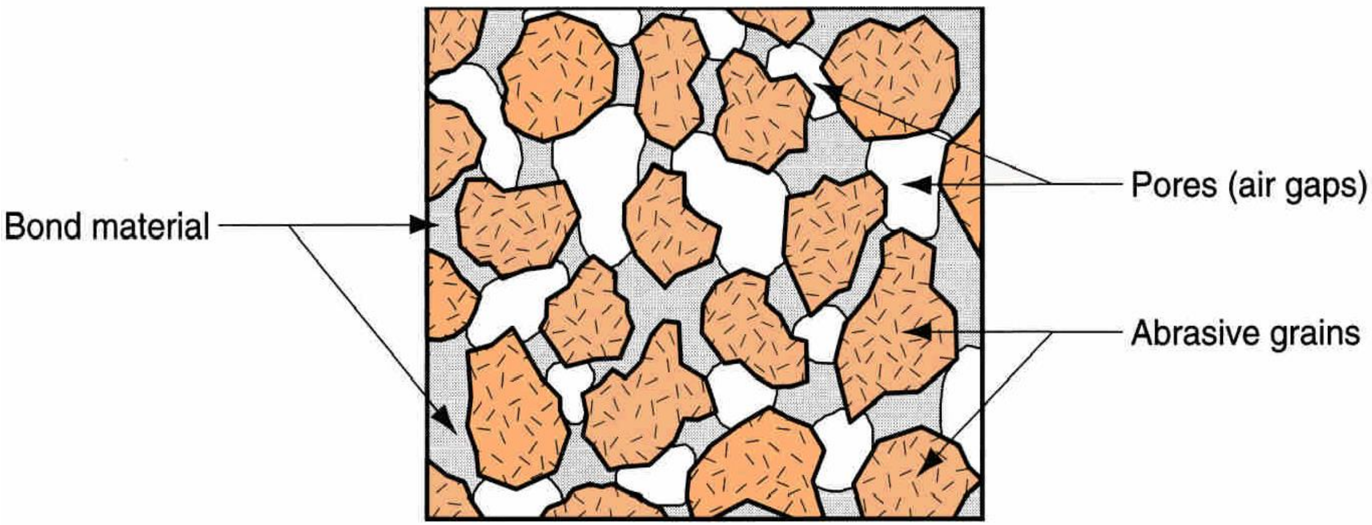
Structure of a grinding wheel is a measure of its *porosity*

Refers to the relative spacing of abrasive grains in a wheel

- In addition to abrasive grains and bond material, grinding wheels contain air gaps or pores
- Volumetric proportions of **g**rains, **b**ond material, and **p**ores can be expressed as:

$$V_g + V_b + V_p = 1.0$$





4. Wheel Structure

Measured on a scale that ranges between "open" and "dense"

- Open structure means:

  V_p is relatively large

  V_g is relatively small

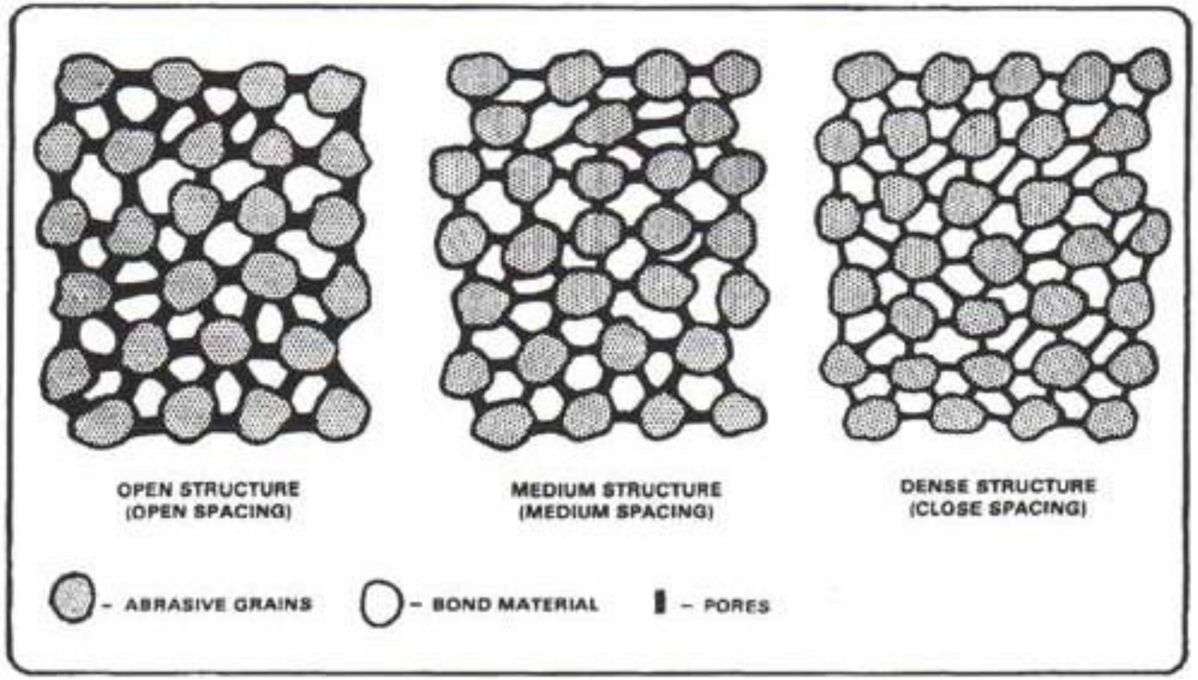
  recommended when clearance for chips must be provided

- Dense structure means:

  V_p is relatively small

  V_g is larger

  recommended to obtain better SF and dimensional control

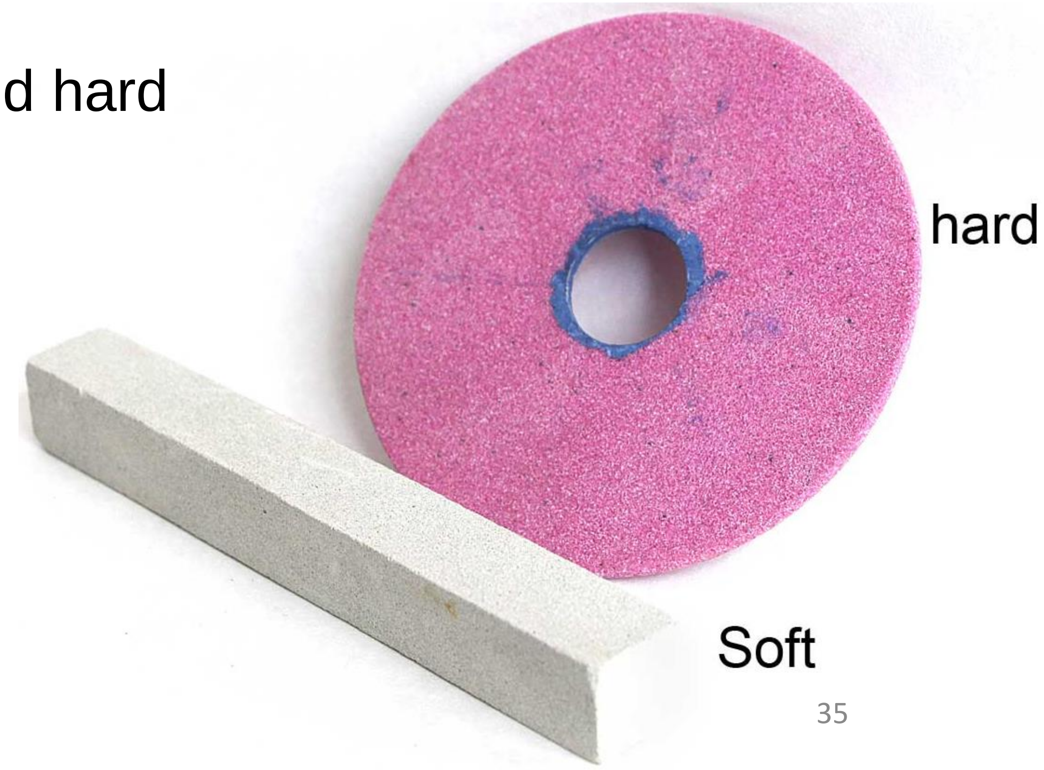


5. Wheel Grade

Example:	51	–	A	–	36	–	L	–	5	–	V	–	23
	Prefix		Abrasive type		Abrasive grain size		Grade		Structure		Bond type		Manufacturer's record

Wheel grade indicates the grinding wheel's bond strength in retaining the abrasive grits during cutting

- This is largely dependent on the amount of bonding material present in the wheel structure (***V_b***)
- Measured on a scale ranging between soft and hard
  - "Soft" wheels lose grains readily – used for low material removal rates and hard work materials
  - "Hard" wheels retain grains – used for high stock removal rates and soft work materials



Grinding Wheel Specification

- Standard grinding wheel marking system used to designate abrasive type, grit size, grade, structure, and bond material
  - Example: A-46-H-6-V
- Also provides for additional identifications for use by grinding wheel manufacturers

Grinding Properties

Surface Finish

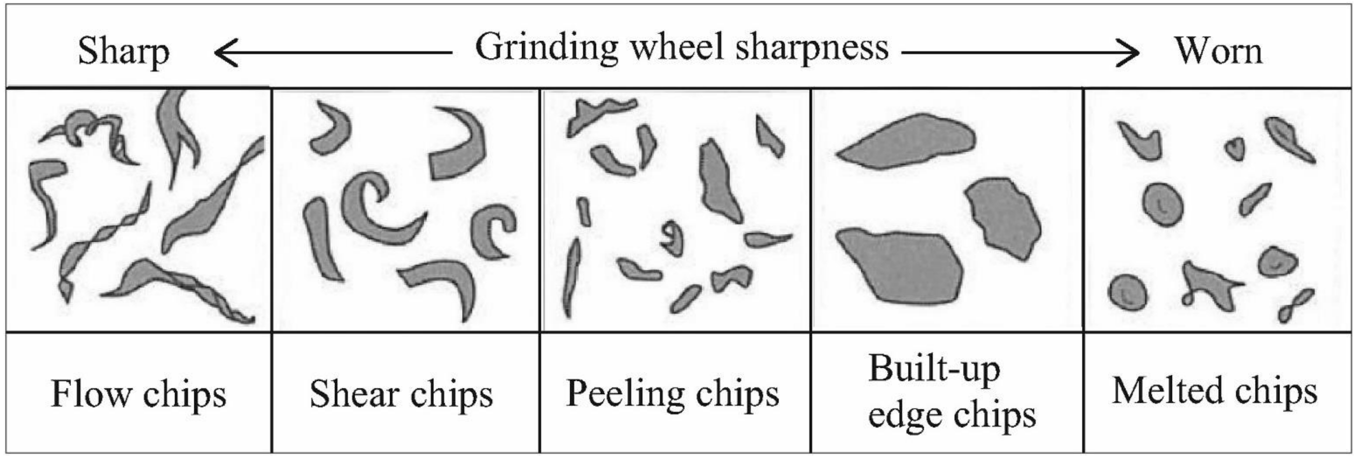
- Most grinding is performed to achieve good surface finish
- Best surface finish is achieved by:
  - Small grain sizes
  - Higher wheel speeds
  - Denser wheel structure = more grits per wheel area

Why Specific Energy in Grinding is High

- *Size effect* - small chip size causes energy needed to remove each unit volume of material to be significantly higher - roughly 10 times higher
- Individual grains have extremely negative rake angles, resulting in low shear plane angles and high shear strains
- Not all grits are engaged in actual cutting

Approximate Specific-energy Requirements for Surface Grinding

Workpiece material	Hardness	Specific energy W · s/mm^3
Aluminum	150 HB	7–27
Cast iron (class 40)	215 HB	12–60
Low-carbon steel (1020)	110 HB	14–68
Titanium alloy	300 HB	16–55
Tool steel (T15)	67 HRC	18–82



Why Specific Energy in Grinding is High

Approximate Range of Energy Requirements in Cutting Operations at the Drive Motor of the Machine Tool (for Dull Tools, Multiply by 1.25)

Material	Specific energy $W \cdot s/mm^3$
Aluminum alloys	0.4–1
Cast irons	1.1–5.4
Copper alloys	1.4–3.2
High-temperature alloys	3.2–8
Magnesium alloys	0.3–0.6
Nickel alloys	4.8–6.7
Refractory alloys	3–9
Stainless steels	2–5
Steels	2–9
Titanium alloys	2–5

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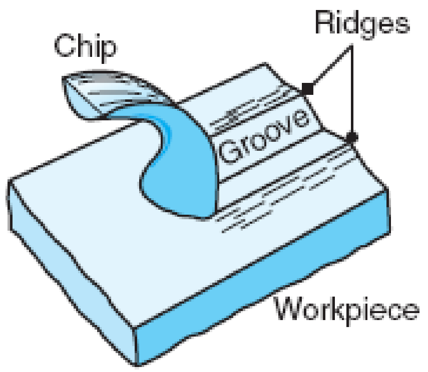
Three Types of Grain Action



- ***Cutting*** - grit projects far enough into surface to form a chip - material is removed
- ***Plowing*** - grit projects into work, but not far enough to cut - instead, surface is deformed plastically and energy is consumed, but no material is removed
- ***Rubbing*** - grit contacts surface but only rubbing friction occurs, thus consuming energy, but no material is removed

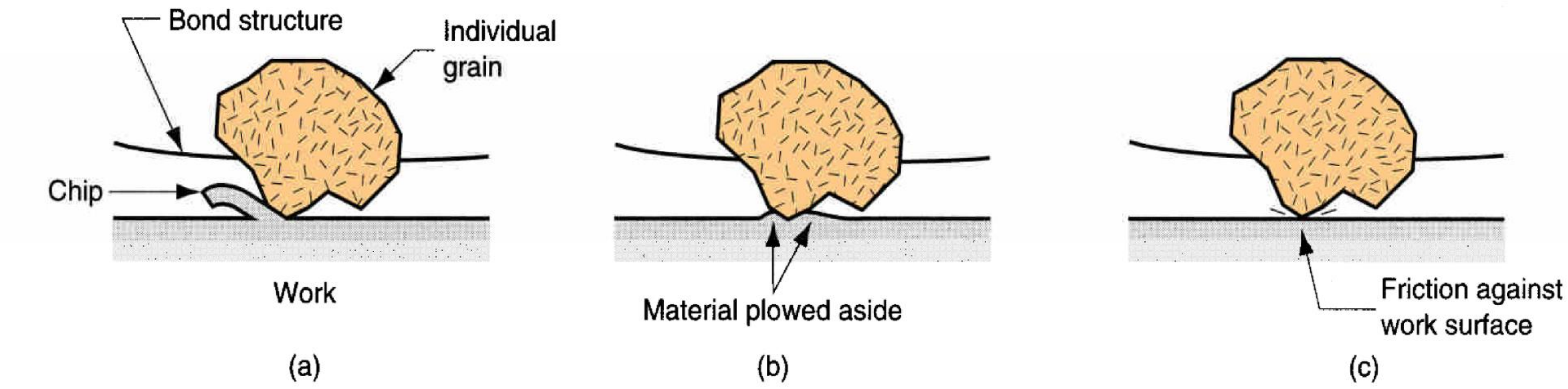


Figure 25.4 - Three types of grain action in grinding:

(a) cutting,

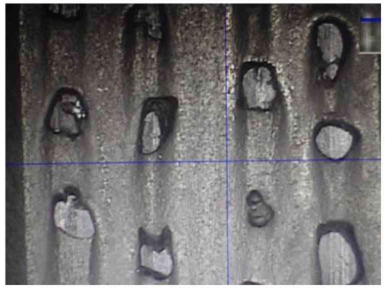
(b) plowing, and

(c) rubbing

Temperatures at the Work Surface

- Grinding is characterized by high temperatures and high friction, and most of the energy remains in the ground surface, resulting in high work surface temperatures

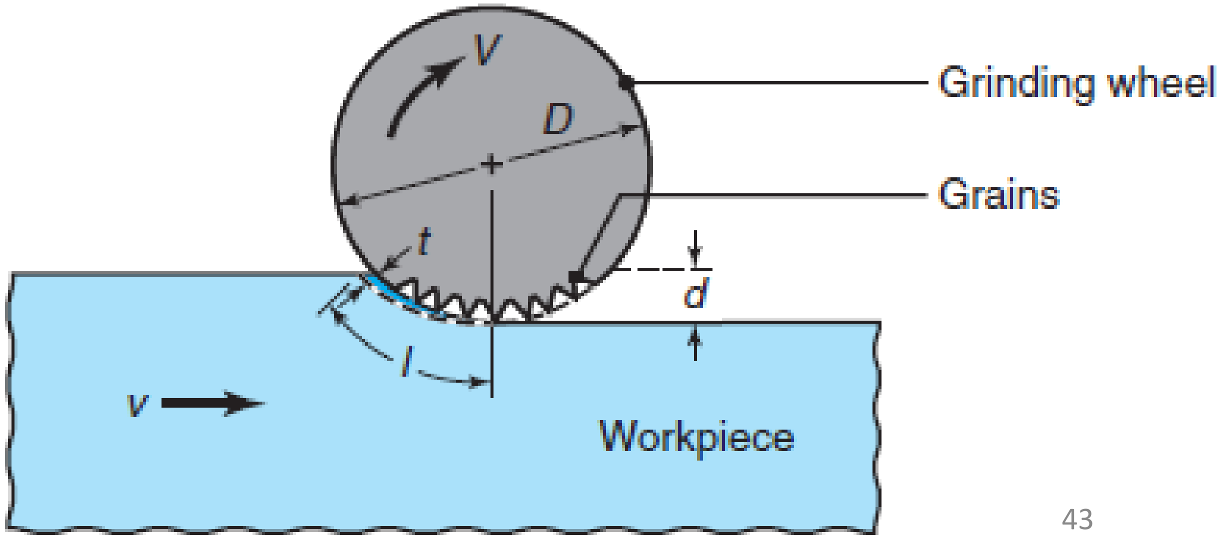
- Damaging effects include:
  - Surface burns and cracks
  - Metallurgical damage immediately beneath the surface
  - Softening of the work surface if heat treated
  - Residual stresses in the work surface



worn-out-dressing-tool (grinding burn)

How to Reduce Work Surface Temperatures

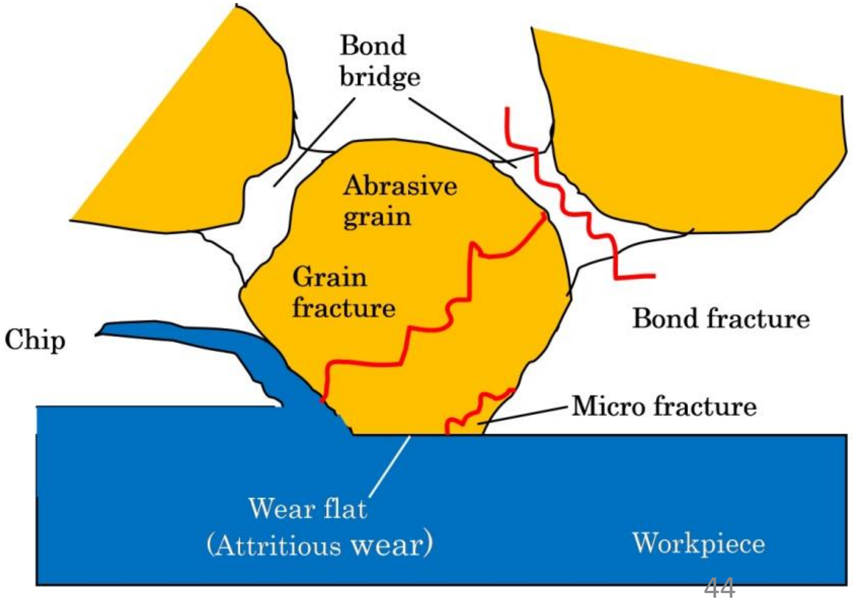
- Decrease infeed (depth of cut) (*d)*
- Reduce wheel speed (*V)*
- Reduce number of active grits per square inch on the grinding wheel or increasing work speed (*f)*
- Use a cutting fluid



Causes of Wheel Wear – 1

Grain fracture - when a portion of the grain breaks off, but the rest remains bonded in the wheel

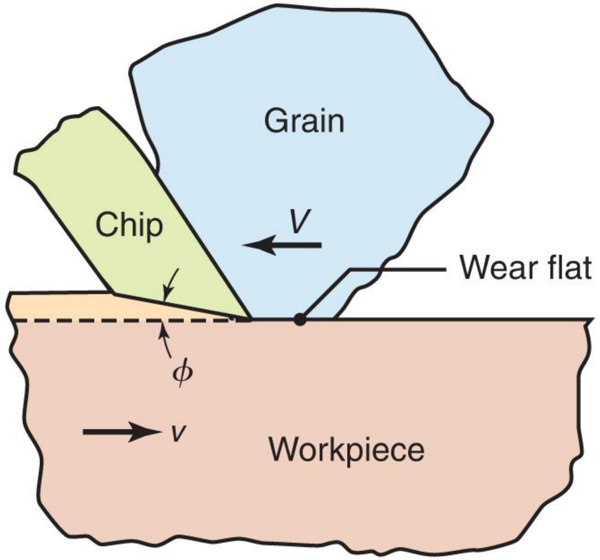
- Edges of the fractured area become new cutting edges
- Tendency to fracture is called *friability*

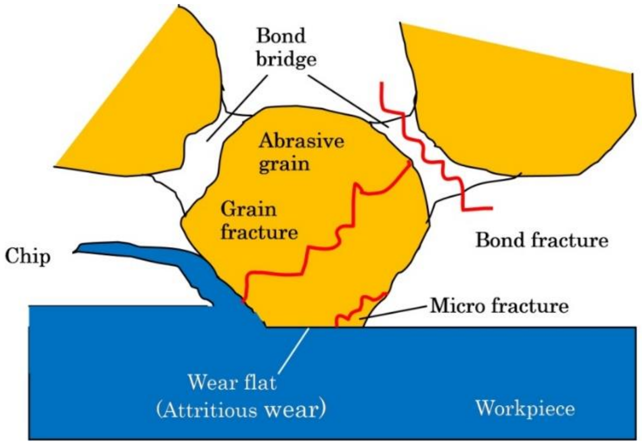


Causes of Wheel Wear - 2

Attritious wear - dulling of individual grains, resulting in flat spots and rounded edges

- Analogous to tool wear in conventional cutting tool
- Caused by similar mechanisms including friction, diffusion, and chemical reactions

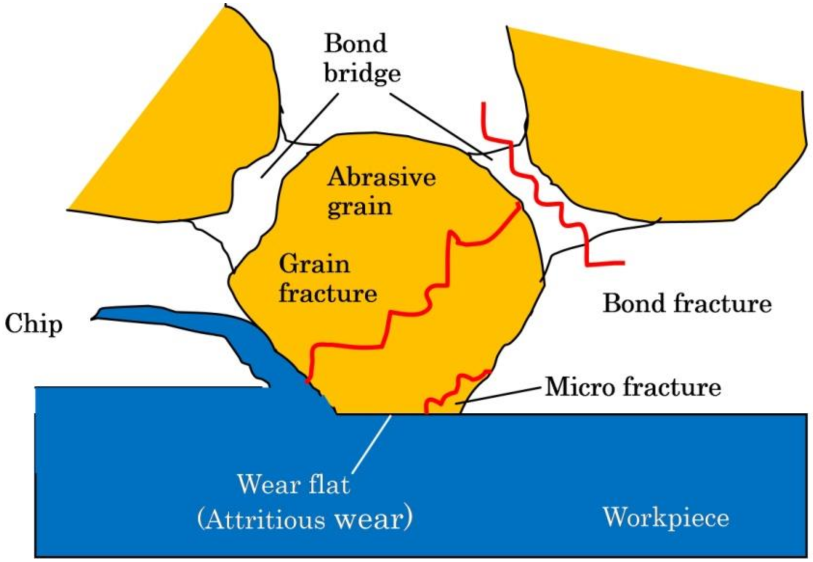




Causes of Wheel Wear - 3

Bond fracture - the individual grains are pulled out of the bonding material

- Depends on wheel grade, among other factors
- Usually occurs because grain has become dull due to attritious wear, and resulting cutting force becomes excessive



Grinding Ratio

Indicates slope of the wheel wear curve

$$GR = \frac{V_w}{V_{gr}}$$

where,

GR = grinding ratio

V_w = volume of work material removed; and

V_{gr} = corresponding volume of grinding wheel worn

Dressing the Wheel

Dressing - accomplished by rotating disk, abrasive stick, or another grinding wheel held against the wheel being dressed as it rotates

- Functions:
  - Breaks off dulled grits to expose new sharp grains
  - Removes chips clogged in the wheel
- Accomplished by a rotating disk, an abrasive stick, or another grinding wheel operating at high speed, held against the wheel being dressed as it rotates

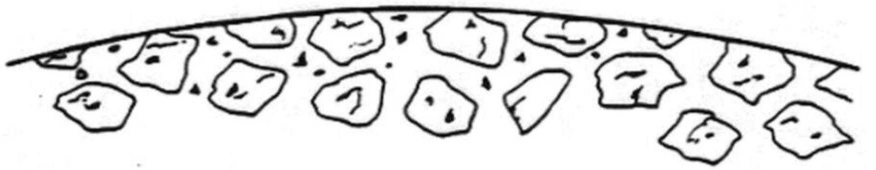
https://www.youtube.com/watch?v=vRIsTcADhC0

Truing the Wheel

Truing - use of a diamond-pointed tool fed slowly and precisely across wheel as it rotates

- Very light depth is taken (0.025 mm or less) against the wheel
- Not only sharpens wheel, but restores cylindrical shape and insures straightness across outside perimeter
  - Although dressing sharpens, it does not guarantee the shape of the wheel

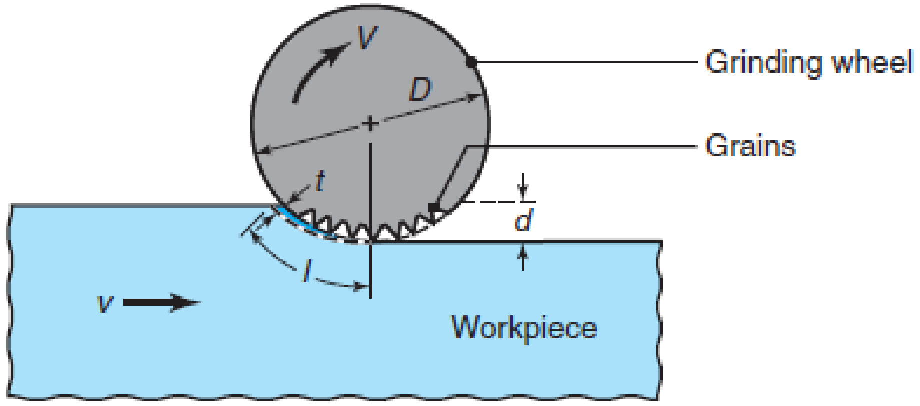
— After Dressing



— After Trueing

https://www.youtube.com/watch?v=Wq2tPttFpC8

Application Guidelines - I



- To optimize surface finish, select
  - Small grit size and dense wheel structure
  - Use higher wheel speeds (*V*) and lower work speeds (*f*)
  - Smaller depths of cut (*d*) and larger wheel diameters (*D*) will also help
- To maximize material removal rate, select
  - Large grit size
  - More open wheel structure
  - Vitrified bond

Application Guidelines - II

- For grinding steel and most cast irons, select
  - Aluminum oxide as the abrasive
- For grinding most nonferrous metals, select
  - Silicon carbide as the abrasive
- For grinding hardened tool steels and certain aerospace alloys, choose
  - Cubic boron nitride as the abrasive
- For grinding hard abrasive materials such as ceramics, cemented carbides, and glass, choose
  - Diamond as the abrasive

Application Guidelines - III

- For soft metals, choose
  - Large grit size and harder grade wheel
- For hard metals, choose
  - Small grit size and softer grade wheel

Types of Grinding

Types of grinding

(Surface Grinding, Cylindrical grinding and centerless grinding)

Surface Grinding

Surface grinding is normally used to **grind plain flat surfaces**; it is performed using either the periphery of the grinding wheel or the flat face of the wheel.

Four types of surface grinding machines are used in surface grinding operation.

a) horizontal spindle with reciprocating worktable
b) horizontal spindle with rotating worktable
c) vertical spindle with reciprocating worktable
d) vertical spindle with rotating worktable.

Types of grinding

Surface Grinding

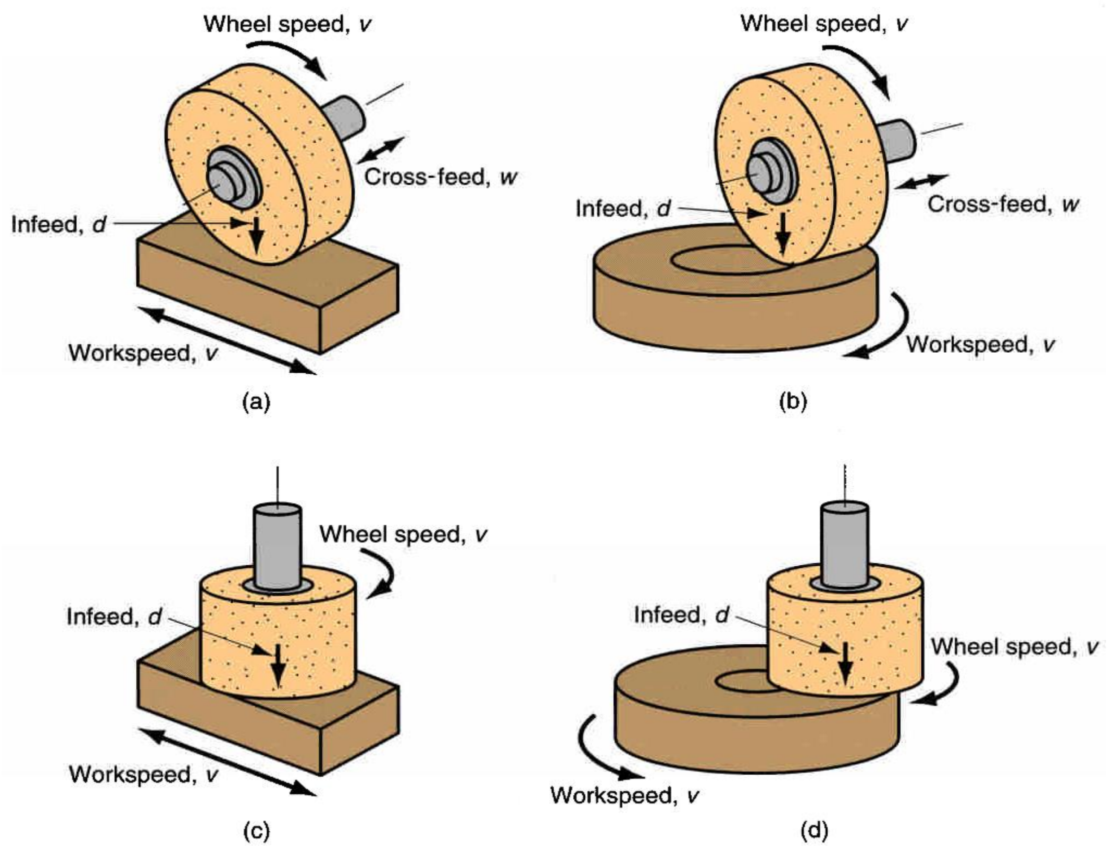


Figure 25.7 - Four types of **surface grinding**: (a) horizontal spindle with reciprocating worktable, (b) horizontal spindle with rotating worktable, (c) vertical spindle with reciprocating worktable, and (d) vertical spindle with rotating worktable

Types of grinding

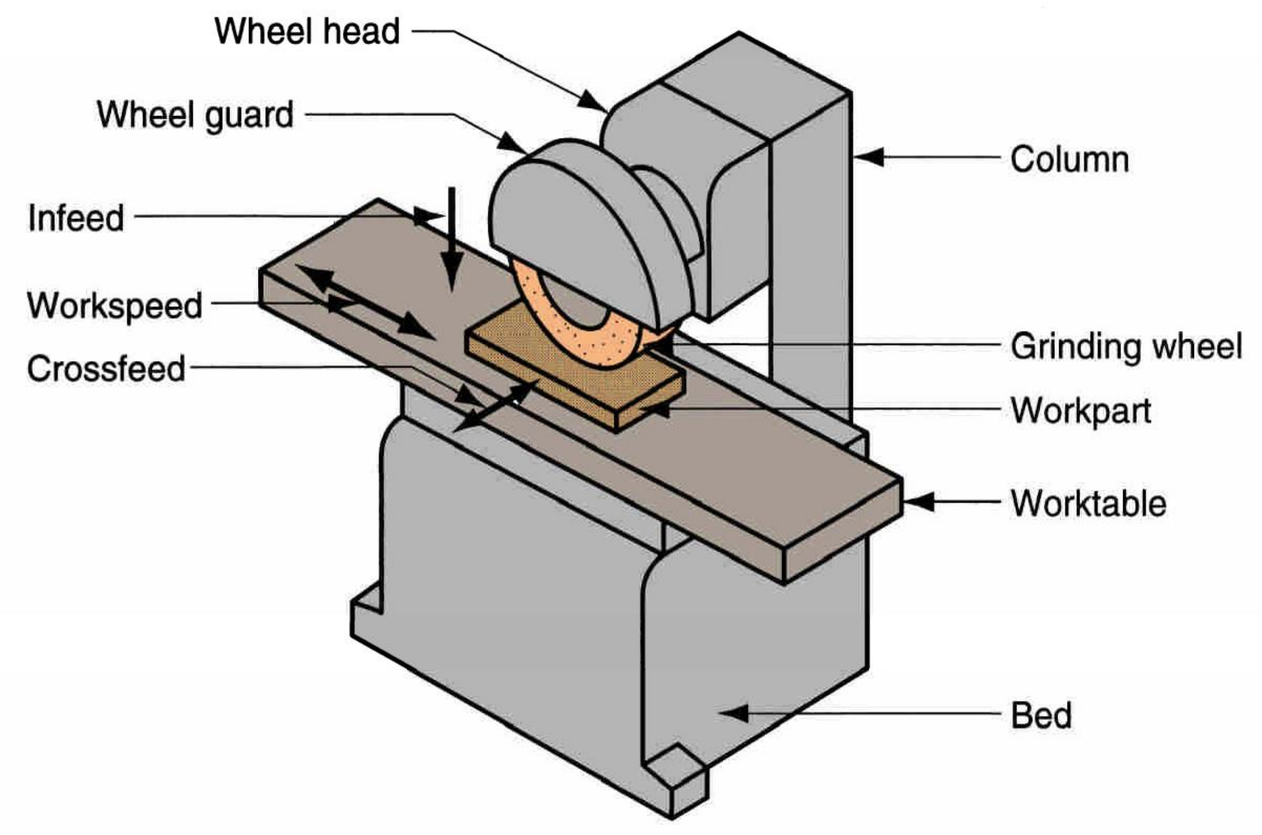


Figure 25.8 - Surface grinder with horizontal spindle and reciprocating worktable (most common grinder type)

Types of grinding

Cylindrical Grinding

Cylindrical grinding as its name suggests, is used for rotational parts; these grinding operations are divided into two basic types.

A. **External cylindrical grinding** which is similar to external turning; the grinding machine used for these operations closely resemble a lathe in which the tool post has been replaced by a high speed motor to rotate the grinding wheel
B. **Internal cylindrical grinding** operates somewhat like a boring operation; the workpiece is usually held in a chuck and rotated to provide surface speed; the wheel is fed in either of two ways: (1) traverse feed or (2) plunge feed

Types of grinding

Cylindrical Grinding

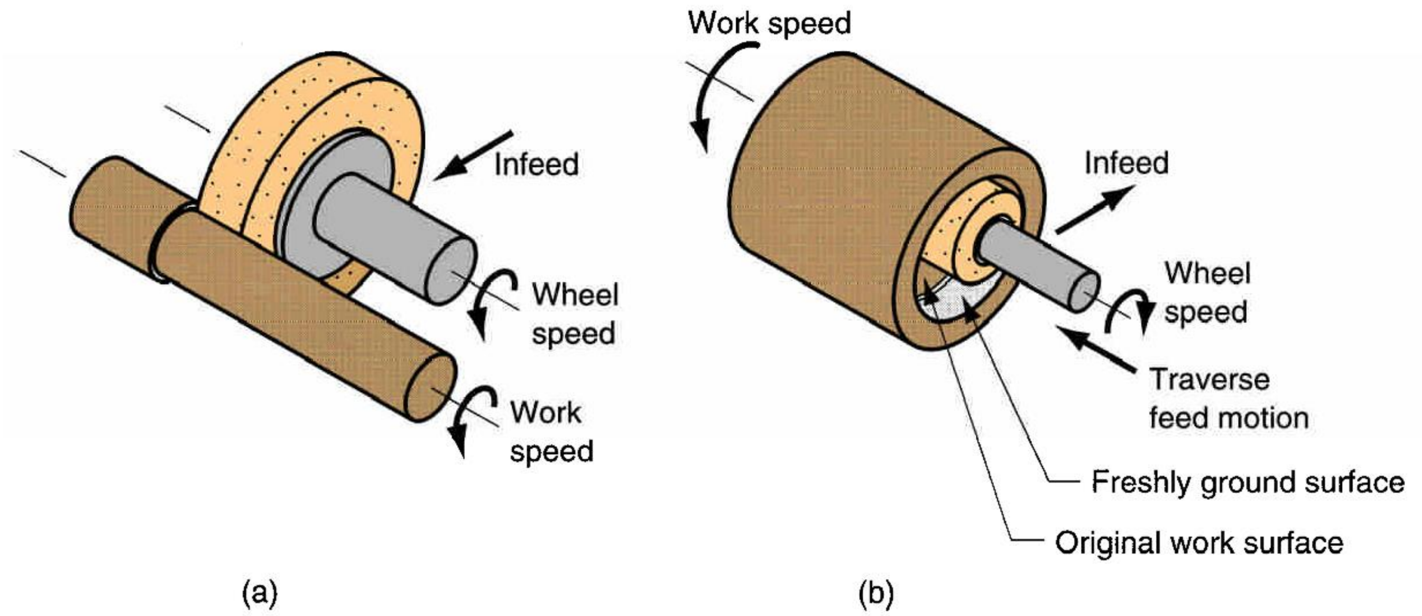


Figure 25.9 - Two types of **cylindrical grinding**:

(a) external, and (b) internal

External: https://www.youtube.com/watch?v=xjbuEjkRs1M
Internal: https://www.youtube.com/watch?v=rr6VUbd_WXY

Types of grinding

Centerless Grinding

- Centerless grinding is an alternative process for grinding external and internal cylindrical surfaces.

- As its name suggests, the workpiece is not held between centers; this results in a reduction in work handling time; hence, centerless grinding is often used for high-production work.

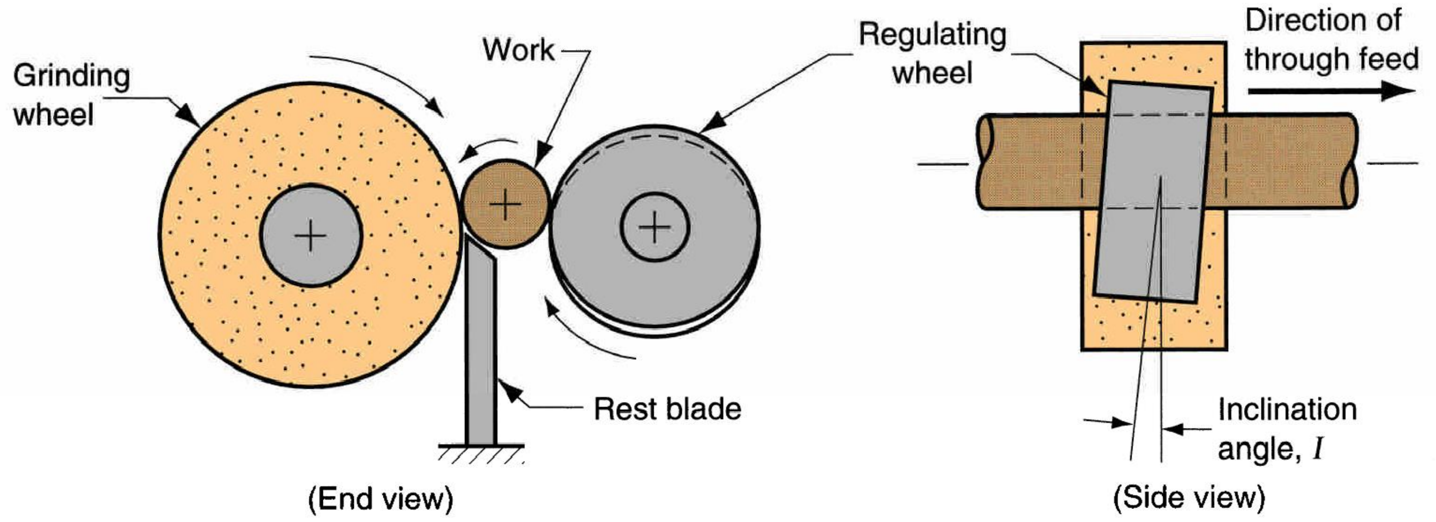


Figure 25.11 - **External centerless grinding**

https://www.youtube.com/watch?v=y3SxF3HsqRo

Types of grinding

Creep Feed Grinding

- Creep feed grinding is performed at very high depths of cut and very low feed rates; hence, the name creep feed
- Depths of cut 1000 to 10,000 times greater than in conventional surface grinding
- Feed rates reduced by about the same proportion
- Material removal rate and productivity are increased in creep feed grinding because the wheel is continuously cutting
- In conventional surface grinding, wheel is engaged in cutting for only a portion of the stroke length

Types of grinding

Creep Feed Grinding

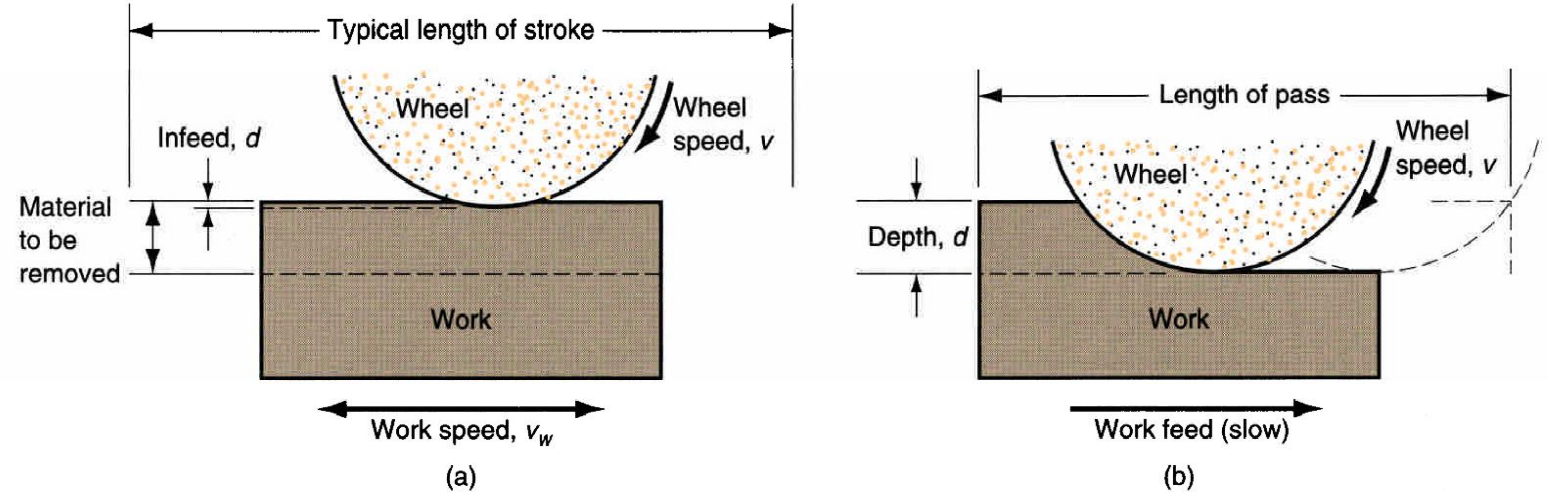


Figure 25.13 - Comparison of (a) conventional surface grinding and (b) creep feed grinding

Related abrasive processes

Related abrasive processes

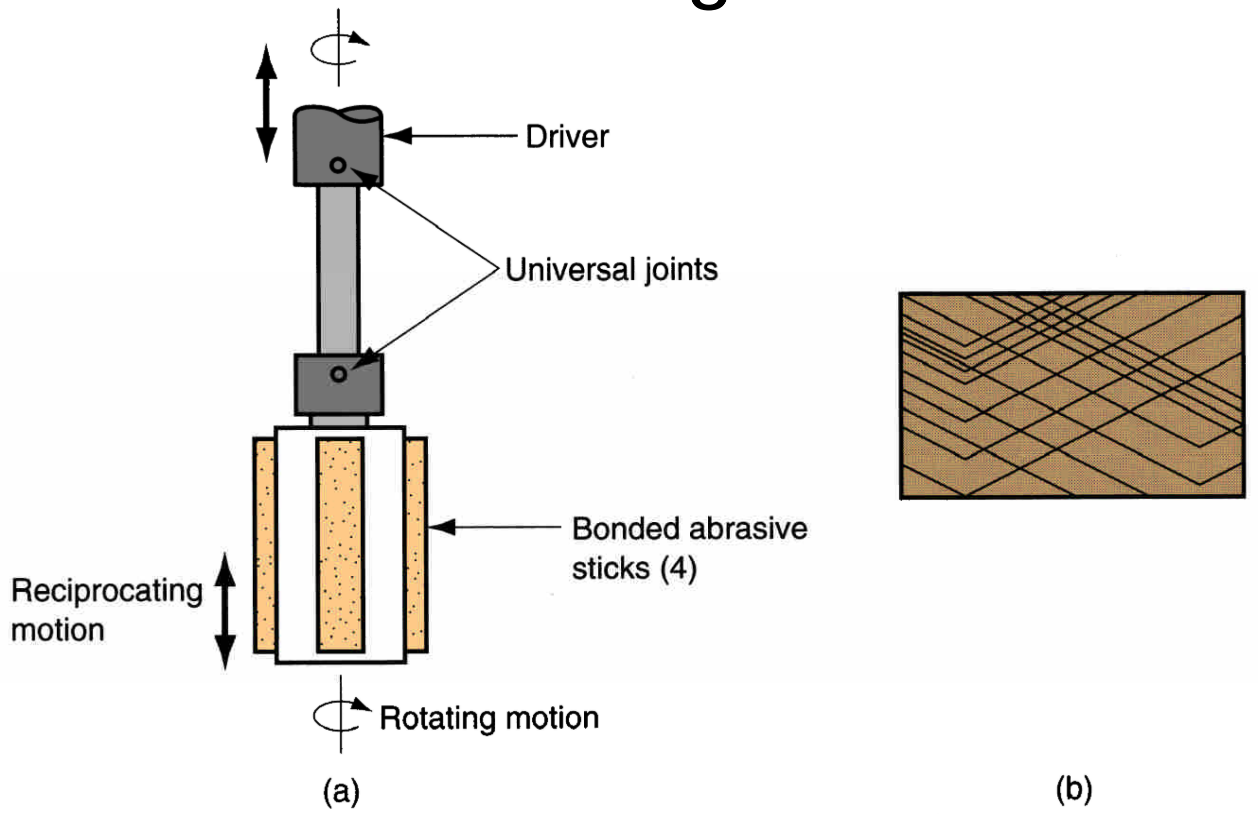
Honing

Abrasive process performed by a set of bonded abrasive sticks using a combination of rotational and oscillatory motions

- Common application is to finish the bores of internal combustion engines
- Grit sizes range between 30 and 600
- Surface finishes of 0.12 μm (5 μ-in) or better
- Creates a characteristic cross-hatched surface that retains lubrication

Related abrasive processes

Honing



https://www.youtube.com/watch?v=dzMTysjhjGQ

https://www.youtube.com/watch?v=Ep6p4amqzfw

Figure 25.16 - The honing process: (a) the honing tool used for internal bore surface, and (b) cross-hatched surface pattern created by the action of the honing tool

Related abrasive processes

Lapping

- Uses a fluid suspension of very small abrasive particles between workpiece and lap (tool)
- *Lapping compound* - fluid with abrasives, general appearance of a chalky paste
- Typical grit sizes between 300 to 600
- Applications: optical lenses, metallic bearing surfaces, gages



Related abrasive processes

Lapping

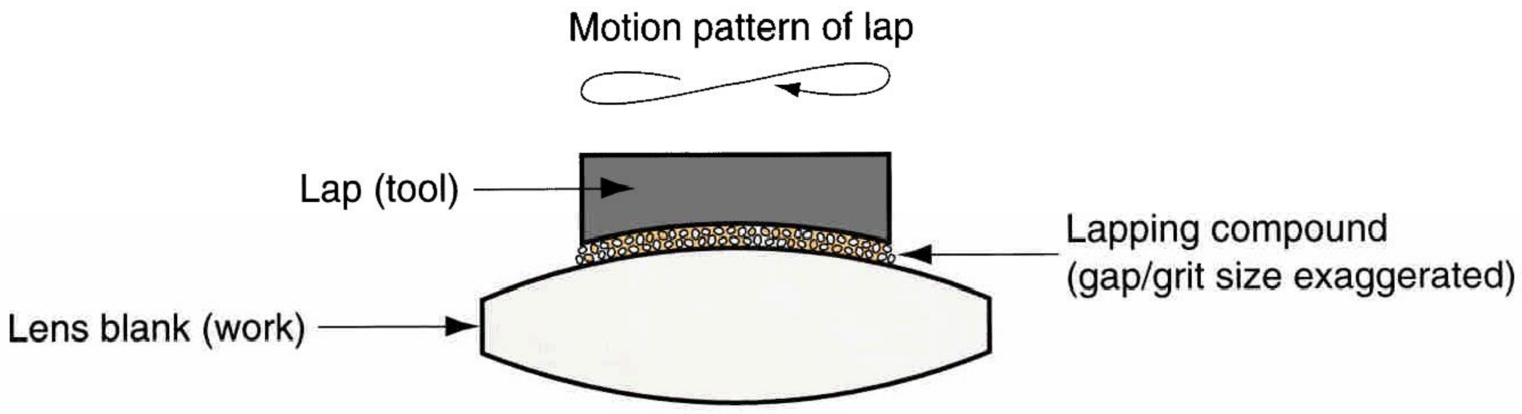


Figure 25.17 - The lapping process in lens-making

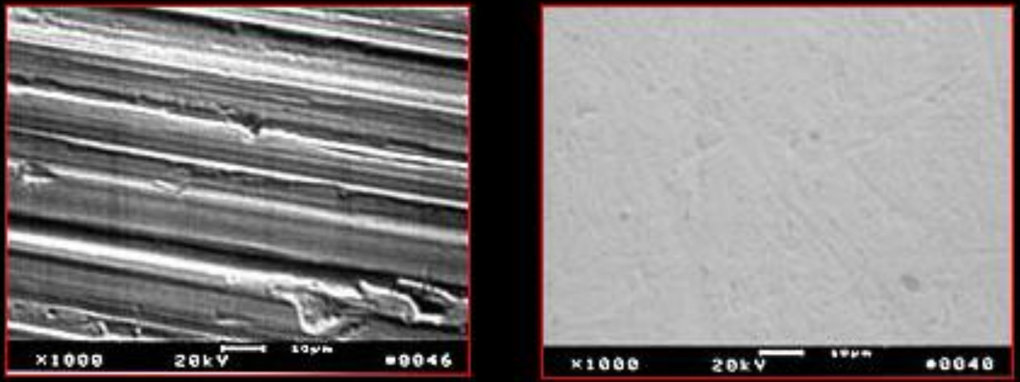
https://www.youtube.com/watch?v=Z6togIVqC4M

Related abrasive processes

Superfinishing

Similar to honing - uses bonded abrasive stick pressed against surface and reciprocating motion

- Differences with honing:
  - Shorter strokes
  - Higher frequencies
  - Lower pressures between tool and surface
  - Smaller grit sizes



The pictures above show the difference between a typical as-machined surface before and after superfinishing.

Related abrasive processes

Superfinishing

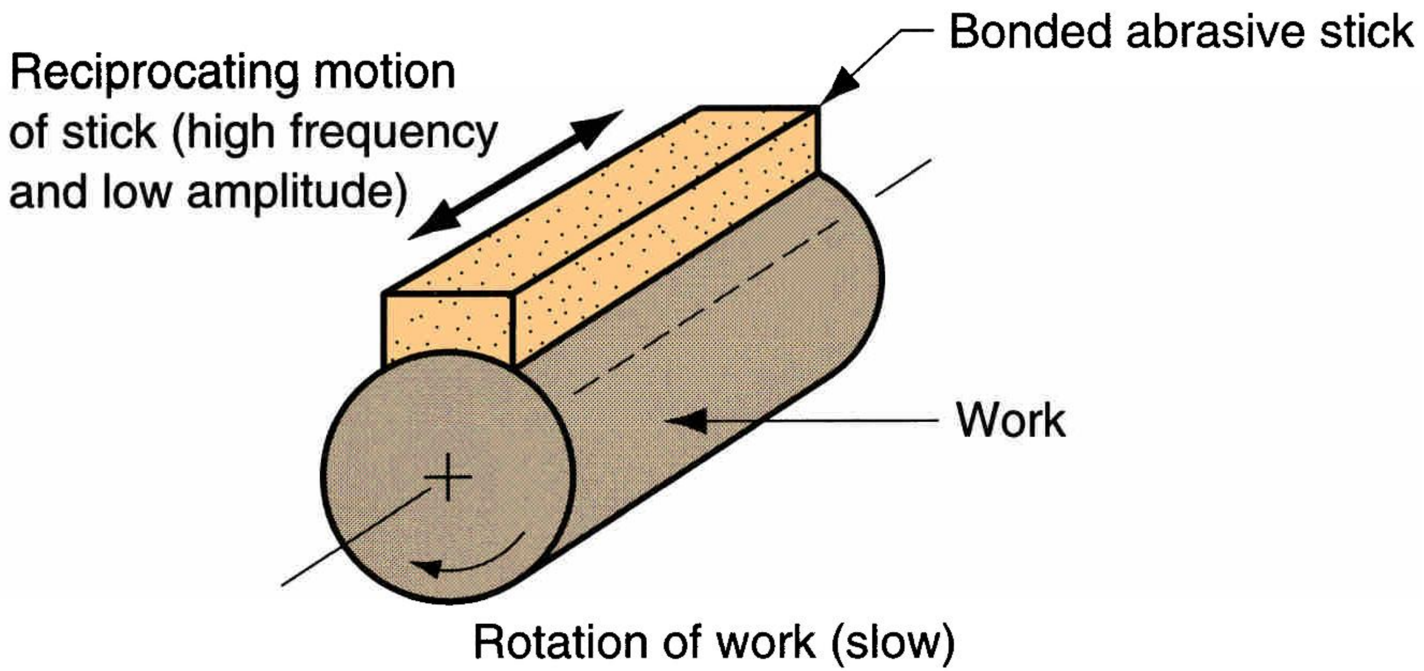


Figure 25.18 - Superfinishing on an external cylindrical surface

https://www.youtube.com/watch?v=-XfgLXnHXoc

Related abrasive processes

https://www.youtube.com/watch?v=gz2Pm3DBOds

https://www.youtube.com/watch?v=wKsvCYG7-Gg